VACCINE COMPOSITIONS CONTAINING AMYLOID BETA1-6 ANTIGEN ARRAYS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention is related to the fields of molecular biology, virology, immunology and medicine. The invention provides a composition comprising an ordered and repetitive antigen or antigenic determinant array, and in particular an Aβ1–6 peptide-VLP-composition. More specifically, the invention provides a composition comprising a virus-like particle and at least one Aβ1–6 peptide bound thereto. The invention also provides a process for producing the conjugates and the ordered and repetitive arrays, respectively. The compositions of the invention are useful in the production of vaccines for the treatment of Alzheimer's disease and as a pharmaccine to prevent or cure Alzheimer's disease and to efficiently induce immune responses, in particular antibody responses. Furthermore, the compositions of the invention are particularly useful to efficiently induce self-specific immune responses within the indicated context.

Related Art

Alzheimer's disease (AD) is the most common cause of dementia among the elderly (age 65 and older) and a serious burden for public health. For example, 4 million people are reported to suffer from the disease in the United Sates of America. The incidence of the disease is expected to increase as the population ages.

The main pathological signs of Alzheimer's disease are age-related changes in behaviour, deposition of β-amyloid into insoluble plaques, called the neuritic plaques or AD plaques, neurofibrillary tangles composed of tau protein within neurons, and loss of neurons throughout the forebrain. In addition to the late onset AD, which occurs in old age (65 years and more), there is an early onset AD, familial AD (FAD) occurring between age 35 and 60. The pathological abnormalities of AD are more widespread, severe and occur earlier in FAD than in late onset or sporadic AD.

Mutations in the APP gene, the presenilin 1 and the presenilin 2 genes have been correlated with FAD.

As indicated, one of the key events in Alzheimer's Disease (AD) is the deposition of amyloid as insoluble fibrous masses (amyloidogenesis) resulting in extracellular neuritic plaques and deposits around the walls of cerebral blood vessels (for review see Selkoe, D. J. (1999) Nature. 399, A23-31). The major constituent of the neuritic plaques and congophilic angiopathy is amyloid ß (Aß), although these deposits also contain other proteins such as glycosaminoglycans and apolipoproteins. Aß is proteolytically cleaved from a much larger glycoprotein known as Amyloid Precursor Protein (APP), which comprises isoforms of 695-770 amino acids with a single hydrophobic transmembrane region. Aß forms a group of peptides up to 43 amino acids in length showing considerable amino- and carboxy-terminal heterogeneity (truncation) as well as modifications (Roher, A. E., Palmer, K. C., Chau, V., & Ball, M. J. (1988) J. Cell Biol. 107, 2703-2716. Roher, A. E., Palmer, K. C., Yurewicz, E. C., Ball, M. J., & Greenberg, B. D. (1993) J. Neurochem. 61, 1916-1926). Prominent isoforms are Aβ1-40 and 1-42. It has a high propensity to form ß-sheets aggregating into fibrils, which ultimately leads to the amyloid.

Aβ peptide has a central role in the neuropathology of Alzheimers disease. Region specific, extracellular accumulation of Aβ peptide is accompanied by microgliosis, cytoskeletal changes, dystrophic neuritis and synaptic loss. These pathological alterations are thought to be linked to the cognitive decline that defines the disease.

Administration of amyloid beta protein or, in particular, Aβ 1-28 in amounts of up to 10^{-2} mg/dose in the absence of any adjuvants and without any linkage of the amyloid beta protein or Aβ 1-28 to a carrier, for the treatment of Alzheimer's disease, is described in EP 526'511.

Others have used administration of Aβ peptides in combination with adjuvants, to induce an immune response, cellular or humoral, against Aβ 1-42. In a transgenic mouse model of Alzheimer disease, animals overexpress human amyloid precursor protein containing the mutation APP(717)V-F (PDAPP-mice; Johnson-Wood, K. *et al., Proc. Natl. Acad. USA 94*: 1550-1555, Games, D. *et al., Nature 373*: 523-527 (1995a)), leading to overproduction of $A\beta_{1-42}$, develop plaques, dystrophic neuritis,

loss of presynaptic terminals, astrocytosis and microgliosis. In a recent study, Schenk, D. *et al.*, (*Nature 400*:173-77 (1999) and WO 99/27944) report that administration of aggregated $A\beta_{1-42}$ mixed with a strong adjuvant (CFA/IFA), which cannot be used in humans, in the first 4 immunizations, followed by administration of aggregated Aβ1–42 in PBS in the subsequent immunizations, to PDAPP-mice at 6 weeks of age, essentially prevented plaque formation and associated dystrophic neuritis. The same authors reported that immunization of older mice (11 months of age) using the same strategy markedly reduced the extent and progression of Alzheimer's disease (AD)-like neuropathologies. Proliferation of splenocytes from mice immunized using the abovementionned strategy was reported in Example III (Screen for therapeutic Efficacy against established AD) of WO 99/27944, showing that Aβ1-42 specific T-cells were induced by the vaccination procedure. Coupling of Aβ fragments to sheep anti-mouse IgG, and immunization of said coupled fragment in the presence of the adjuvant CFA/IFA is reported in WO 9927944. The use of compositions comprising Aβ fragments linked to polypeptides such as diphtheria toxin for promoting an immune response against Aβ is also disclosed in WO 99/27944. However, no data of immunization are provided.

A monoclonal antibody recognizing an epitope within the N-terminus (1-16) of Aβ (antibody 6C6) has been shown to protect PC12 cells from neurotoxicity of fibrillar β-amyloid, and to disaggregate β-amyloid in vitro (Solomon B. et al., Proc.Natl. Acad. Sci. USA (1997)). A monoclonal antibody raised against Aβ1-28, was also shown to suppress β-amyloid aggregation in vitro (Solomon B. et al., Proc. Natl. Acad. Sci. USA (1996)). Frenkel et al., (J. Neuroimmunol. 88: 85-90 (1998)) have later identified the epitope of two anti-aggregating antibodies, 10D5 and 6C6, as being the epitope "EFRH", i.e. Aβ3-6. In contrast, an antibody specific for Aβ1-7 was unable to prevent β-amyloid aggregation (Frenkel D. et al., J. Neuroimmunol. 95: 136-142 (1999)).

Aβ1-42 is fibrillogenic, and indeed, the vaccine composition described in WO 99/27944 used Aβ1-42 treated in such a way that it can form aggregates. It has been shown that those fibrils are toxic for neuronal cell cultures (Yankner *et al., Science 245*: 417-420 (1989)), and that a toxic effect is also observed when injected into animal brains (Sigurdson *et al., Neurobiol. Aging 17*: 893-901 (1996); Sigurdson *et*

al., Neurobiol. Aging 18: 591-608 (1997)). Walsh et al., (*Nature 416*:535-539 (2002)) report that natural oligomers of Aβ are formed within intracellular vesicles. Those oligomers inhibited long term potentiation in rats in vivo and disrupted synaptic plasticity at concentrations found in human brain and cerebrospinal fluid.

In another study, Bard, F. *et al.* (*Nature Medicine 6*:916-19 (2000)) reported that peripheral administration of antibodies raised against $A\beta_{1-42}$, was able to reduce amyloid burden, despite relatively modest serum levels. This study utilized either polyclonal antibodies raised against $A\beta_{1-42}$, or monoclonal antibodies raised against synthetic fragments derived from different regions of Aβ. Thus induction of antibodies against Aβ peptides bears promises as a potential therapeutic treatment for Alzheimer disease.

Mucosal administration of an antigen associated with β-amyloid plaques, such as β-amyloid peptide and Aβ1-40, has been described in WO99/27949. Mucosal administration is said to suppress certain cytokine responses associated with Alzheimer's disease, and to enhance certain other cytokine responses associated with the suppression of inflammatory responses linked to the disease. It is thought that suppression of the inflammatory responses is effected by the "elicitation of T-cells characterized by an anti-inflammatory cytokine profile". Suitable antigens, as described in WO9927949, include antigens specific for AD, and which are recognized by immune T-cells of a human or animal host.

Fusion of epitopes of a monoclonal antibody recognizing Aβ to coat proteins of filamentous phages is described in WO 01/18169. Immunization of mice with the filamentous phages displaying the 15-mer epitope VHEPHEFRHVALNPV (SEQ ID NO: 89) on the coat protein VIII resulted in antibodies recognizing Aβ 1-16, and Aβ1-40. This was demonstrated in an inhibition ELISA using Aβ peptides, and an IC50 of 1 μM was found for inhibition of the binding of the sera to Aβ1-16 with Aβ1-40. Solomon (WO 01/18169), however, provides no indication that the sera elicited against the filamentous phages carrying the VHEPHEFRHVALNPV epitope (SEQ ID NO: 89), bind to amyloid plaques or neuritic plaques of AD.

There are a number of drawbacks in using sequences differing from the antigen against which an immune response is to be elicited for immunization. First,

antibodies against part of the sequence foreign to the antigen or antigenic determinant may be induced. Second, the conformation of the antigen in the context of the foreign flanking sequence element may be different than in the context of the full-length antigen. Thus, although antibodies cross-reacting to the antigen may be elicited, their binding to the antigen may be suboptimal. The fine specificity of those elicited antibody may also not correspond to the specificity of antibodies elicited against the antigen itself, as additional sid-chains different from the residues present on the full-length Aβ are present in the epitope. Finally, a 15-mer amino-acid sequence may contain T-cell epitopes. Display of the epitope YYEFRH (SEQ ID NO: 90) on the protein III of filamentous phage coat, of which 3-5 copies only are usually present on each phage, is also disclosed in WO 01/18169. Several problems arise when using infectious phages as carrier for immunization. First, production of infectious agents in large scale and in sufficient quantity for large immunization campaigns is problematic. Second, the presence of the DNA of the phage containing antibiotic resistance genes in the vaccine is not unproblematic and is a safety issue. Finally, the feasibility and efficacy of irradiation of large quantities of phages, in the case where non-infectious phages are used as vaccine, is unresolved.

Aβ analogues, wherein Aβ is modified to include T helper epitopes have been described (WO 01/62284). Immunization of TgRND8+ mice, transgenic for human APP, with the Aβ analogue resulted in a 4- to 7.5-fold higher antibody titer over immunization with Aβ1-42 in the absence of adjuvant.

Recent studies demonstrated that a vaccination-induced reduction in brain amyloid deposits has the potential to improve cognitive functions (Schenk, D., *et al. Nature 400*: 173-177 (1999); Janus, C. *et al., Nature 408*: 979-982 (2000); Morgan, D. *et al., Nature 408* : 982-985 (2000)).

The autopsy of a patient immunised with aggregated Aβ1-42 in the Adjuvant QS21 has revealed the presence of a T-lymphocyte meningoencephalitis and infiltration of cerebral white matter by macrophages (Nicoll, J.A. et al., Nature Med. 9: 448-452 (2003)).

Recently, a publication has reported 18 cases of meningoencephalitis in patients immunized by the AN1792, a vaccine composed of aggregated Aβ1-42 and QS-21 as adjuvant (Orgogozo J.-M. et al., Neurology 61: 46-54 (2003)). T-cell

activation is reported as a potential mechanism responsible for the disease, while there was no clear relation between disease and anti-Aβ1-42 titers in the serum.

It is well established that the administration of purified proteins alone is usually not sufficient to elicit a strong immune response; isolated antigen generally must be given together with helper substances called adjuvants. Within these adjuvants, the administered antigen is protected against rapid degradation, and the adjuvant provides an extended release of a low level of antigen. In the present invention, Aβ peptides are made immunogenic through binding to a VLP and do not require an adjuvant.

One way to improve the efficiency of vaccination is thus to increase the degree of repetitiveness of the antigen applied. Unlike isolated proteins, viruses induce prompt and efficient immune responses in the absence of any adjuvants both with and without T -cell help (Bachmann and Zinkernagel, *Ann. Rev. Immunol: 15*:235-270 (1991)). Although viruses often consist of few proteins, they are able to trigger much stronger immune responses than their isolated components. For B-cell responses, it is known that one crucial factor for the immunogenicity of viruses is the repetitiveness and order of surface epitopes. Many viruses exhibit a quasi-crystalline surface that displays a regular array of epitopes which efficiently crosslinks epitope-specific immunoglobulins on B cells (Bachmann and Zinkernagel, *Immunol. Today 17*:553-558 (1996)). This crosslinking of surface immunoglobulins on B cells is a strong activation signal that directly induces cell-cycle progression and the production of IgM antibodies. Further, such triggered B cells are able to activate T helper cells, which in turn induce a switch from IgM to IgG antibody production in B cells and the generation of long-lived B cell memory - the goal of any vaccination (Bachmann and Zinkernagel, *Ann. Rev. Immunol. 15*:235-270 (1997)). Viral structure is even linked to the generation of anti-antibodies in autoimmune disease and as a part of the natural response to pathogens (see Fehr, T., *et al., J Exp. Med. 185*:1785-1792 (1997)). Thus, antibodies presented by a highly organized viral surface are able to induce strong anti-antibody responses.

As indicated, however, the immune system usually fails to produce antibodies against self-derived structures. For soluble antigens present at low concentrations, this is due to tolerance at the Th cell level. Under these conditions, coupling the self-

antigen to a carrier that can deliver T help may break tolerance. For soluble proteins present at high concentrations or membrane proteins at low concentration, B and Th cells may be tolerant. However, B cell tolerance may be reversible (anergy) and can be broken by administration of the antigen in a highly organized fashion coupled to a foreign carrier (Bachmann and Zinkernagel, *Ann. Rev. Immunol. 15*:235-270 (1997)). As shown in pending U.S. Application No. 10/050,902 filed on January 18, 2002, strong immune responses could be induced with compositions comprising Aβ peptides (Aβ1-15, Aβ1-27 and Aβ33-42, which is a self-antigen in mice) bound to a VLP. In particular, the abovementionned human Aβ peptides bound to the VLP of RNA phage Qβ induced high Aβ specific titers in human APP transgenic mice (described in Example) demonstrating that tolerance to the self-antigen Aβ could be overcome by immunizing with Aβ peptides bound to a VLP.

There is thus a need for highly immunogenic safe compositions and vaccines, respectively, to treat Alzheimer diseases, in particular, using immunogens devoid of T-cell epitopes and adjuvants, respectively, which might elicit side-effects, and still being capable of inducing high antibody titers, which antibodies, furthermore, being capable of binding to amyloid plaques.

BRIEF SUMMARY OF THE INVENTION

We have now found that Aβ1-6 peptide, which is bound to a core particle having a structure with an inherent repetitive organization, and hereby in particular to virus-like-particles (VLPs) and subunits of VLPs, respectively, leading to highly ordered and repetitive conjugates represent a potent immunogen for the induction of antibodies specific for Aβ1-6. Therefore, the present invention provides a prophylactic and therapeutic mean for the treatment of Alzheimer's disease, which is based on an ordered and repetitive Aβ1-6 -core particle array, and in particular on a VLP-Aβ1-6 peptide conjugate and -array, respectively. This prophylactic and therapeutic is able to induce high titers of anti-Aβ1-6 peptide antibodies, which are cross-reactive to soluble Aβ and are capable of binding to human amyloid plaques of a human APP transgenic mouse model and to AD amyloid plaques. Furthermore, the elicited antibodies do not bind to APP on brain sections.

Moreover, the present invention provides for new compositions, vaccines and methods of treatment of AD. The compositions and vaccines comprising Aβ 1-6 peptides are devoid of T-cell epitopes and induce antibodies binding AD plaques and soluble Aβ. The Aβ 1-6 peptides are presented to the immune system of the patient in a highly repetitive and ordered fashion through binding of the Aβ peptides or to a core particle, preferably to a VLP, and even more preferably to a VLP of a RNA phage.

In a preferred embodiment, the antigen or antigenic determinant is the human amyloid beta peptide Aβ1-6 (DAEFRH; SEQ ID NO: 75) being a fragment of Aβ (DAEFRHDSGYEVHHQKLVFFAEDVGSNKGAIIGLMVGGVVIA (SEQ ID NO: 91), wherein the human amyloid beta peptide Aβ1-6 is bound to the core particle and VLP, respectively. The amyloid beta protein is provided in SEQ ID NO: 92. The amyloid beta precursor protein is provided in SEQ ID NO: 93.

The present invention, thus, provides for a composition comprising: (a) a core particle with at least one first attachment site; and (b) at least one antigen or antigenic determinant with at least one second attachment site, wherein said antigen or antigenic determinant is a Aβ1-6 peptide, and wherein said second attachment site being selected from the group consisting of (i) an attachment site not naturally occurring with said antigen or antigenic determinant; and (ii) an attachment site naturally occurring with said antigen or antigenic determinant, wherein said second attachment site is capable of association to said first attachment site; and wherein said antigen or antigenic determinant and said core particle interact through said association to form an ordered and repetitive antigen array. Preferred embodiments of core particles suitable for use in the present invention are a virus, a virus-like particle, a bacteriophage, a virus-like particle of a RNA-phage, a bacterial pilus or flagella or any other core particle having an inherent repetitive structure capable of forming an ordered and repetitive antigen array in accordance with the present invention.

The Aβ fragments of the present invention are soluble and generally do not form aggregates. Moreover, they are bound, and preferably covalently bound to a core particle and VLP, respectively. Therefore, the compositions of the invention do not bear the risk of inducing toxic effects such as seeding of amyloid deposition.

It is an unexpected finding of this invention that a high titer of antibodies cross-reactive with soluble Aβ and AD amyloid plaques could be obtained with a composition comprising the Aβ1-6 peptide bound to a a core particle and VLP, respectively. In particular, VLP have been shown to mediate induction of antibodies against self antigens, thus breaking self-tolerance (WO 02/056905, the disclosure of which is herewith incorporated by reference in its entirety). Furthermore, the small size of this epitope precludes the presence of T-cell epitopes, thus providing new compositions that do not induce Aβ specific T-cell responses. In addition, the elicited antibodies do not bind to APP on brain sections. Thus, the present invention provides for a safe vaccine composition for the prevention and treatment of AD.

More specifically, the invention provides a composition comprising an ordered and repetitive antigen or antigenic determinant array, and hereby in particular Aβ1-6 peptide VLP conjugates. More specifically, the invention provides a composition comprising a virus-like particle and at least one Aβ1-6 peptide bound thereto. The invention also provides a process for producing the conjugates and the ordered and repetitive arrays, respectively. The compositions of the invention are useful in the production of vaccines for the treatment of Alzheimer's disease and as a pharmaccine to prevent or cure Alzheimer's disease and to efficiently induce immune responses, in particular antibody responses. Furthermore, the compositions of the invention are particularly useful to efficiently induce self-specific immune responses within the indicated context.

In the present invention, a Aβ1-6 peptide is bound to a core particle and VLP, respectively, typically in an oriented manner, yielding an ordered and repetitive Aβ1-6 peptide antigen array. Furthermore, the highly repetitive and organized structure of the core particles and VLPs, respectively, mediates the display of the Aβ peptide in a highly ordered and repetitive fashion leading to a highly organized and repetitive antigen array. Furthermore, binding of the Aβ1-6 peptide to the core particle and VLP, respectively, provides T helper cell epitopes, since the core particle and VLP is foreign to the host immunized with the core particle- Aβ1-6 peptide array and VLP-Aβ1-6 peptide array, respectively. Those arrays differ from prior art conjugates, in particular, in their highly organized structure, dimensions, and in the repetitiveness of the antigen on the surface of the array.

In one aspect of the invention, the Aβ1-6 peptide is chemically synthesized, while the core particle and the VLP, repespectively, is expressed and purified from an expression host suitable for the folding and assembly of the core particle and the VLP, repespectively. The Aβ1-6 peptide array is then assembled by binding the Aβ1-6 peptide to the core particle and the VLP, repespectively.

In another aspect, the present invention provides for a composition comprising (a) a virus-like particle, and (b) at least one antigen or antigenic determinant, wherein said antigen or said antigenic determinant is an Aβ1-6 peptide, and wherein said at least one antigen or antigenic determinant is bound to said virus-like particle.

In a further aspect, the present invention provides for a pharmaceutical composition comprising (a) the inventive composition, and (b) an acceptable pharmaceutical carrier.

In still a further aspect, the present invention provides for a vaccine composition comprising a composition, wherein said composition comprising (a) a virus-like particle; and (b) at least one antigen or antigenic determinant, wherein said antigen or said antigenic determinant is a Aβ1-6 peptide; and wherein said at least one antigen or antigenic determinant is bound to said virus-like particle.

In another aspect, the present invention provides for a method of immunization comprising administering the inventive composition, the inventive pharmaceutical composition or the inventive vaccine to an animal.

In still a further aspect, the present invention provides for a process for producing an inventive composition comprising (a) providing a virus-like particle; and (b) providing at least one antigen or antigenic determinant, wherein said antigen or said antigenic determinant is a Aβ1-6 peptide; (c) combining said virus-like particle and said at least one antigen or antigenic determinant so that said at least one antigen or antigenic determinant is bound to said virus-like particle.

Analogously, the present invention provides a process for producing a composition of claim 1 comprising: (a) providing a core particle with at least one first attachment site; (b) providing at least one antigen or antigenic determinant with at least one second attachment site, wherein said antigen or antigenic determinant is a Aβ1-6 peptide, and wherein said second attachment site being selected from the group consisting of (i) an attachment site not naturally occurring with said antigen or

antigenic determinant; and (ii) an attachment site naturally occurring with said antigen or antigenic determinant; and wherein said second attachment site is capable of association to said first attachment site; and (c) combining said core particle and said at least one antigen or antigenic determinant, wherein said antigen or antigenic determinant and said core particle interact through said association to form an ordered and repetitive antigen array.

In a further aspect, the present invention provides for a use of a composition of claim 1 for the manufacture of a medicament for treatment of Alzheimer's disease.

In a still further aspect, the present invention provides for a use of a composition of claim 1 for the preparation of a medicament for the therapeutic or prophylactic treatment of Alzheimer's disease. Furthermore, in a still further aspect, the present invention provides for a use of a composition of claim 1, either in isolation or in combination with other agents, or with explicit absence of specific substances such as adjuvants, for the manufacture of a composition, pharmaceutical composition, vaccine, drug or medicament for therapy or prophylaxis of Alzheimer's disease, and/or for stimulating the mammalian immune system.

Therefore, the invention provides, in particular, vaccine compositions which are suitable for preventing and/or attenuating Alzheimer's disase or conditions related thereto. The invention further provides immunization and vaccination methods, respectively, for preventing and/or attenuating Alzheimer's disease or conditions related thereto in humans. The inventive compositions may be used prophylactically or therapeutically.

In specific embodiments, the invention provides methods for preventing and/or attenuating Alzheimer's disease or conditions related thereto which are caused or exacerbated by "self" gene products, i.e. "self antigens" as used herein. In related embodiments, the invention provides methods for inducing immunological responses in animals and individuals, respectively, which lead to the production of antibodies that prevent and/or attenuate Alzheimer's disease or conditions related thereto, which are caused or exacerbated by "self" gene products.

As would be understood by one of ordinary skill in the art, when compositions of the invention are administered to an animal or a human, they may be in a composition which contains salts, buffers, adjuvants, or other substances which are

desirable for improving the efficacy of the composition. Examples of materials suitable for use in preparing pharmaceutical compositions are provided in numerous sources including *Remington's Pharmaceutical Sciences* (Osol, A, ed., Mack Publishing Co. (1990)).

Compositions of the invention are said to be "pharmacologically acceptable" if their administration can be tolerated by a recipient individual. Further, the compositions of the invention will be administered in a "therapeutically effective amount" (*i.e.*, an amount that produces a desired physiological effect).

The compositions of the present invention may be administered by various methods known in the art, but will normally be administered by injection, infusion, inhalation, oral administration, or other suitable physical methods. The compositions may alternatively be administered intramuscularly, intravenously, or subcutaneously. Components of compositions for administration include sterile aqueous (*e.g.*, physiological saline) or non-aqueous solutions and suspensions. Examples of non-aqueous solvents are propylene glycol, polyethylene glycol, vegetable oils such as olive oil, and injectable organic esters such as ethyl oleate. Carriers or occlusive dressings can be used to increase skin permeability and enhance antigen absorption.

Other embodiments of the present invention will be apparent to one of ordinary skill in light of what is known in the art, the following drawings and description of the invention, and the claims.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 depicts the SDS-PAGE gel, run under reducing conditions, showing the result of the coupling of the Aβ1-6 peptide (NH2-DAEFRHGGC-CONH2) (SEQ ID NO: 77) to the VLP of Qβ coat protein.

FIG. 2 shows the ELISA analysis of the antibodies specific for Aβ1-6 in sera of mice immunized with Aβ1-6 peptide coupled to the VLP of Qβ coat protein.

FIG. 3 shows the ELISA analysis of the antibodies specific for Aβ1-40 in sera of mice immunized with Aβ1-6 peptide coupled to the VLP of Qβ coat protein.

FIG. 4 A-B show a brain section of an APP23 mouse (A) and an entorhinal cortex section from an AD patient (B) stained with sera of mice immunized with Aβ1-6 peptide coupled to the VLP of Qβ coat protein.

FIG. 5 A-E show brain sections of an APP23 mouse stained with sera of mice immunized with Aβ1-6 peptide coupled to the VLP of Qβ coat protein, or with a polyclonal rabbit antiserum specific for the C-terminus of human or mouse APP.

FIG.6 shows the result of the immunization of rhesus monkeys with human Aβ1-6 coupled to Qβ VLP as measured in an ELISA assay.

FIG. 7 shows the result of the binding to plaques of sera from monkeys immunized with human Aβ1-6 coupled to Qβ VLP, as measured by histology on human AD and transgenic mouse plaques.

FIG. 8 depicts the SDS-PAGE analysis of the coupling of murine Aβ1-6 to AP205 VLP.

FIG. 9 shows the result of the immunisation of mice with murine Aβ1-6 coupled to AP205 as measured in an ELISA assay.

FIG. 10 shows the analysis by ELISA of the anti-Aβ40 and anti-Aβ42 titers in the sera of "Swedish/London" transgenic mice immunized with QβhAβ1-6 between 9.5 and 19 months of age.

FIG. 11 shows the immunohistochemical staining of brain sections of "Swedish/London" transgenic mice immunized with QβhAβ1-6 or PBS .

FIG. 12 shows the quantification of plaque deposition in "Swedish/London" transgenic mice immunized with QβhAβ1-6, Qβ or PBS between 9.5 and 19 months of age.

FIG. 13 shows the quantification of plaque deposition in "Swedish/London" transgenic mice immunized with QβhAβ1-6 or PBS between 13.5 and 19 months of age.

FIG. 14 shows the analysis by ELISA of the anti-Aβ40 and anti-Aβ42 titers in the sera of "Swedish" transgenic mice immunized with QβhAβ1-6.

FIG. 15 shows the immunohistochemical staining of brain sections from "Swedish" transgenic mice immunized with QβhAβ1-6 or PBS.

FIG. 16 shows the quantification of plaque deposition in "Swedish" transgenic mice immunized with QβhAβ1-6 or PBS.

DETAILED DESCRIPTION OF THE INVENTION

Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art to which this invention belongs. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, the preferred methods and materials are hereinafter described.

1. Definitions:

Aβ1-6 peptide: An Aβ1-6 peptide as used herein refers to peptides having a sequence corresponding to the human Aβ1-6 sequence, or homologous to the human Aβ1-6 sequence. Sequences homologuous to the human Aβ1-6 sequence include, but are not limited to the Aβ1-6 sequences of other species and hereby including, but not limited to, the sequence of primate, rabbit, guinea pig, Xenopus Laevis, frog, mouse and rat Aβ1-6. The Aβ1-6 sequences from Xenopus Laevis or frog, although differing from human Aβ1-6 at two positions, have conservative mutations (Ala-Ser, Phe-Tyr), and are still considered to be homologuous to Aβ1-6 in accordance with this definition. In accordance with the present invention, however, the Aβ1-6 peptide is typically modified, such that a second attachment site is attached thereto. Preferably, the second attachment site is modified with a linker or an amino acid linker comprising a second attachment site for binding to a core particle and VLP, respectively. While referring herein to Aβ1-6 peptides, a modified Aβ1-6 peptide, as indicated above, i.e. Aβ1-6 peptides with a second attachment site attached thereto, shall be encompassed. Typically, however, the modifications are explicitly indicated in the specification. Further preferred embodiments of an Aβ1-6 peptide being an antigen or antigenic determinant in accordance with the present invention become apparent as this specification proceeds.

Adjuvant: The term "adjuvant" as used herein refers to non-specific stimulators of the immune response or substances that allow generation of a depot in the host

which when combined with the vaccine and pharmaceutical composition, respectively, of the present invention may provide for an even more enhanced immune response. A variety of adjuvants can be used. Examples include complete and incomplete Freund's adjuvant, aluminum hydroxide and modified muramyldipeptide. Further adjuvants are mineral gels such as aluminum hydroxide, surface active substances such as lysolecithin, pluronic polyols, polyanions, peptides, oil emulsions, keyhole limpet hemocyanins, dinitrophenol, and potentially useful human adjuvants such as BCG (bacille Calmette-Guerin) and *Corynebacterium parvum*. Such adjuvants are also well known in the art. Further adjuvants that can be administered with the compositions of the invention include, but are not limited to, Monophosphoryl lipid immunomodulator, AdjuVax 100a, QS-21, QS-18, CRL1005, Aluminum salts (Alum), MF-59, OM-174, OM-197, OM-294, and Virosomal adjuvant technology. The adjuvants can also comprise a mixture of these substances.

Immunologically active saponin fractions having adjuvant activity derived from the bark of the South American tree Quillaja Saponaria Molina are known in the art. For example QS21, also known as QA21, is an Hplc purified fraction from the Quillaja Saponaria Molina tree and it's method of its production is disclosed (as QA21) in U.S. Pat. No. 5,057,540. Quillaja saponin has also been disclosed as an adjuvant by Scott et al, Int. Archs. Allergy Appl. Immun., 1985, 77, 409. Monosphoryl lipid A and derivatives thereof are known in the art. A preferred derivative is 3 de-o-acylated monophosphoryl lipid A, and is known from British Patent No. 2220211. Further preferred adjuvants are described in WO00/00462, the disclosure of which is herein incorporated by reference.

However, an advantageous feature of the present invention is the high immunogenicty of the inventive compositions. As already outlined herein or will become apparent as this specification proceeds, vaccines and pharmaceutical compositions devoid of adjuvants are provided, in further alternative or preferred embodiments, leading to vaccines and pharmaceutical compositions for treating AD being devoid of adjuvants and, thus, having a superior safety profile since adjuvants may cause side-effects. The term "devoid" as used herein in the context of vaccines

and pharmaceutical compositions for treating AD refers to vaccines and pharmaceutical compositions that are used without adjuvants.

Amino acid linker: An "amino acid linker", or also just termed "linker" within this specification, as used herein, either associates the antigen or antigenic determinant with the second attachment site, or more preferably, already comprises or contains the second attachment site, typically - but not necessarily - as one amino acid residue, preferably as a cysteine residue. The term "amino acid linker" as used herein, however, does not intend to imply that such an amino acid linker consists exclusively of amino acid residues, even if an amino acid linker consisting of amino acid residues is a preferred embodiment of the present invention. The amino acid residues of the amino acid linker are, preferably, composed of naturally occuring amino acids or unnatural amino acids known in the art, all-L or all-D or mixtures thereof. However, an amino acid linker comprising a molecule with a sulfhydryl group or cysteine residue is also encompassed within the invention. Such a molecule comprise preferably a C1-C6 alkyl-, cycloalkyl (C5,C6), aryl or heteroaryl moiety. However, in addition to an amino acid linker, a linker comprising preferably a C1-C6 alkyl-, cycloalkyl- (C5,C6), aryl- or heteroaryl- moiety and devoid of any amino acid(s) shall also be encompassed within the scope of the invention. Association between the antigen or antigenic determinant or optionally the second attachment site and the amino acid linker is preferably by way of at least one covalent bond, more preferably by way of at least one peptide bond.

Animal: As used herein, the term "animal" is meant to include, for example, humans, sheep, elks, deer, mule deer, minks, mammals, monkeys, horses, cattle, pigs, goats, dogs, cats, rats, mice, birds, chicken, reptiles, fish, insects and arachnids.

Antibody: As used herein, the term "antibody" refers to molecules which are capable of binding an epitope or antigenic determinant. The term is meant to include whole antibodies and antigen-binding fragments thereof, including single-chain antibodies. Most preferably the antibodies are human antigen binding antibody fragments and include, but are not limited to, Fab, Fab' and F(ab')2, Fd, single-chain Fvs (scFv), single-chain antibodies, disulfide-linked Fvs (sdFv) and fragments comprising either a V_L or V_H domain. The antibodies can be from any animal origin including birds and mammals. Preferably, the antibodies are human, murine, rabbit,

goat, guinea pig, camel, horse or chicken. As used herein, "human" antibodies include antibodies having the amino acid sequence of a human immunoglobulin and include antibodies isolated from human immunoglobulin libraries or from animals transgenic for one or more human immunoglobulins and that do not express endogenous immunoglobulins, as described, for example, in U.S. Patent No. 5,939,598 by Kucherlapati *et al.*

Antigen: As used herein, the term "antigen" refers to a molecule capable of being bound by an antibody or a T cell receptor (TCR) if presented by MHC molecules. The term "antigen", as used herein, also encompasses T-cell epitopes. An antigen is additionally capable of being recognized by the immune system and/or being capable of inducing a humoral immune response and/or cellular immune response leading to the activation of B- and/or T-lymphocytes. This may, however, require that, at least in certain cases, the antigen contains or is linked to a Th cell epitope and is given in adjuvant. An antigen can have one or more epitopes (B- and T- epitopes). The specific reaction referred to above is meant to indicate that the antigen will preferably react, typically in a highly selective manner, with its corresponding antibody or TCR and not with the multitude of other antibodies or TCRs which may be evoked by other antigens. Antigens as used herein may also be mixtures of several individual antigens.

Antigenic determinant: As used herein, the term "antigenic determinant" is meant to refer to that portion of an antigen that is specifically recognized by either B- or T-lymphocytes. B-lymphocytes responding to antigenic determinants produce antibodies, whereas T-lymphocytes respond to antigenic determinants by proliferation and establishment of effector functions critical for the mediation of cellular and/or humoral immunity.

Association: As used herein, the term "association" as it applies to the first and second attachment sites, refers to the binding of the first and second attachment sites that is preferably by way of at least one non-peptide bond. The nature of the association may be covalent, ionic, hydrophobic, polar or any combination thereof, preferably the nature of the association is covalent.

Attachment Site, First: As used herein, the phrase "first attachment site" refers to an element of non-natural or natural origin, to which the second attachment site

located on the antigen or antigenic determinant may associate. The first attachment site may be a protein, a polypeptide, an amino acid, a peptide, a sugar, a polynucleotide, a natural or synthetic polymer, a secondary metabolite or compound (biotin, fluorescein, retinol, digoxigenin, metal ions, phenylmethylsulfonylfluoride), or a combination thereof, or a chemically reactive group thereof. The first attachment site is located, typically and preferably on the surface, of the core particle such as, preferably the virus-like particle. Multiple first attachment sites are present on the surface of the core and virus-like particle, respectively, typically in a repetitive configuration.

Attachment Site, Second: As used herein, the phrase "second attachment site" refers to an element associated with the antigen or antigenic determinant to which the first attachment site located on the surface of the core particle and virus-like particle, respectively, may associate. The second attachment site of the antigen or antigenic determinant may be a protein, a polypeptide, a peptide, a sugar, a polynucleotide, a natural or synthetic polymer, a secondary metabolite or compound (biotin, fluorescein, retinol, digoxigenin, metal ions, phenylmethylsulfonylfluoride), or a combination thereof, or a chemically reactive group thereof. At least one second attachment site is present on the antigen or antigenic determinant. The term "antigen or antigenic determinant with at least one second attachment site" refers, therefore, to an antigen or antigenic construct comprising at least the antigen or antigenic determinant and the second attachment site. However, in particular for a second attachment site, which is of non-natural origin, i.e. not naturally occurring within the antigen or antigenic determinant, these antigen or antigenic constructs comprise an "amino acid linker".

Bound: As used herein, the term "bound" refers to binding or attachment that may be covalent, *e.g.*, by chemically coupling, or non-covalent, *e.g.*, ionic interactions, hydrophobic interactions, hydrogen bonds, etc. Covalent bonds can be, for example, ester, ether, phosphoester, amide, peptide, imide, carbon-sulfur bonds, carbon-phosphorus bonds, and the like. The term "bound" is broader than and includes terms such as "coupled," "fused" and "attached".

Coat protein(s): As used herein, the term "coat protein(s)" refers to the protein(s) of a bacteriophage or a RNA-phage capable of being incorporated within

the capsid assembly of the bacteriophage or the RNA-phage. However, when referring to the specific gene product of the coat protein gene of RNA-phages the term "CP" is used. For example, the specific gene product of the coat protein gene of RNA-phage Qβ is referred to as "Qβ CP", whereas the "coat proteins" of bacteriophage Qβ comprise the "Qβ CP" as well as the A1 protein. The capsid of Bacteriophage Qβ is composed mainly of the Qβ CP, with a minor content of the A1 protein. Likewise, the VLP Qβ coat protein contains mainly Qβ CP, with a minor content of A1 protein.

Core particle: As used herein, the term "core particle" refers to a rigid structure with an inherent repetitive organization. A core particle as used herein may be the product of a synthetic process or the product of a biological process.

Coupled: The term "coupled", as used herein, refers to attachment by covalent bonds or by strong non-covalent interactions, typically and preferably to attachment by covalent bonds. Any method normally used by those skilled in the art for the coupling of biologically active materials can be used in the present invention.

Effective Amount: As used herein, the term "effective amount" refers to an amount necessary or sufficient to realize a desired biologic effect. An effective amount of the composition would be the amount that achieves this selected result, and such an amount could be determined as a matter of routine by a person skilled in the art. For example, an effective amount for treating an immune system deficiency could be that amount necessary to cause activation of the immune system, resulting in the development of an antigen specific immune response upon exposure to antigen. The term is also synonymous with "sufficient amount."

The effective amount for any particular application can vary depending on such factors as the disease or condition being treated, the particular composition being administered, the size of the subject, and/or the severity of the disease or condition. One of ordinary skill in the art can empirically determine the effective amount of a particular composition of the present invention without necessitating undue experimentation.

Epitope: As used herein, the term "epitope" refers to continuous or discontinuous portions of a polypeptide having antigenic or immunogenic activity in an animal, preferably a mammal, and most preferably in a human. An epitope is

recognized by an antibody or a T cell through its T cell receptor in the context of an MHC molecule. An "immunogenic epitope," as used herein, is defined as a portion of a polypeptide that elicits an antibody response or induces a T-cell response in an animal, as determined by any method known in the art. (*See*, for example, Geysen *et al.*, *Proc. Natl. Acad. Sci. USA 81*:3998-4002 (1983)). The term "antigenic epitope," as used herein, is defined as a portion of a protein to which an antibody can immunospecifically bind its antigen as determined by any method well known in the art. Immunospecific binding excludes non-specific binding but does not necessarily exclude cross-reactivity with other antigens. Antigenic epitopes need not necessarily be immunogenic. Antigenic epitopes can also be T-cell epitopes, in which case they can be bound immunospecifically by a T-cell receptor within the context of an MHC molecule.

An epitope can comprise 3 amino acids in a spatial conformation which is unique to the epitope. Generally, an epitope consists of at least about 5 such amino acids, and more usually, consists of at least about 8-10 such amino acids. If the epitope is an organic molecule, it may be as small as Nitrophenyl.

Fusion: As used herein, the term "fusion" refers to the combination of amino acid sequences of different origin in one polypeptide chain by in-frame combination of their coding nucleotide sequences. The term "fusion" explicitly encompasses internal fusions, *i.e.*, insertion of sequences of different origin within a polypeptide chain, in addition to fusion to one of its termini.

Immune response: As used herein, the term "immune response" refers to a humoral immune response and/or cellular immune response leading to the activation or proliferation of B- and/or T-lymphocytes and/or and antigen presenting cells. In some instances, however, the immune responses may be of low intensity and become detectable only when using at least one substance in accordance with the invention. "Immunogenic" refers to an agent used to stimulate the immune system of a living organism, so that one or more functions of the immune system are increased and directed towards the immunogenic agent. An "immunogenic polypeptide" is a polypeptide that elicits a cellular and/or humoral immune response, whether alone or linked to a carrier in the presence or absence of an adjuvant. Preferably, antigen presenting cell may be activated.

A substance which "enhances" an immune response refers to a substance in which an immune response is observed that is greater or intensified or deviated in any way with the addition of the substance when compared to the same immune response measured without the addition of the substance. For example, the lytic activity of cytotoxic T cells can be measured, *e.g.* using a ^{51}Cr release assay, in samples obtained with and without the use of the substance during immunization. The amount of the substance at which the CTL lytic activity is enhanced as compared to the CTL lytic activity without the substance is said to be an amount sufficient to enhance the immune response of the animal to the antigen. In a preferred embodiment, the immune response in enhanced by a factor of at least about 2, more preferably by a factor of about 3 or more. The amount or type of cytokines secreted may also be altered. Alternatively, the amount of antibodies induced or their subclasses may be altered.

Immunization: As used herein, the terms "immunize" or "immunization" or related terms refer to conferring the ability to mount a substantial immune response (comprising antibodies and/or cellular immunity such as effector CTL) against a target antigen or epitope. These terms do not require that complete immunity be created, but rather that an immune response be produced which is substantially greater than baseline. For example, a mammal may be considered to be immunized against a target antigen if the cellular and/or humoral immune response to the target antigen occurs following the application of methods of the invention.

Natural origin: As used herein, the term “natural origin” means that the whole or parts thereof are not synthetic and exist or are produced in nature.

Non-natural: As used herein, the term generally means not from nature, more specifically, the term means from the hand of man.

Non-natural origin: As used herein, the term "non-natural origin" generally means synthetic or not from nature; more specifically, the term means from the hand of man.

Ordered and repetitive antigen or antigenic determinant array: As used herein, the term "ordered and repetitive antigen or antigenic determinant array" generally refers to a repeating pattern of antigen or antigenic determinant, characterized by a typically and preferably uniform spacial arrangement of the antigens or antigenic

determinants with respect to the core particle and virus-like particle, respectively. In one embodiment of the invention, the repeating pattern may be a geometric pattern. Typical and preferred examples of suitable ordered and repetitive antigen or antigenic determinant arrays are those which possess strictly repetitive paracrystalline orders of antigens or antigenic determinants, preferably with spacings of 0.5 to 30 nanometers, more preferably 5 to 15 nanometers.

Pili: As used herein, the term "pili" (singular being "pilus") refers to extracellular structures of bacterial cells composed of protein monomers (*e.g.*, pilin monomers) which are organized into ordered and repetitive patterns. Further, pili are structures which are involved in processes such as the attachment of bacterial cells to host cell surface receptors, inter-cellular genetic exchanges, and cell-cell recognition. Examples of pili include Type-1 pili, P-pili, F1C pili, S-pili, and 987P-pili. Additional examples of pili are set out below.

Pilus-like structure: As used herein, the phrase "pilus-like structure" refers to structures having characteristics similar to that of pili and composed of protein monomers. One example of a "pilus-like structure" is a structure formed by a bacterial cell which expresses modified pilin proteins that do not form ordered and repetitive arrays that are identical to those of natural pili.

Polypeptide: As used herein, the term "polypeptide" refers to a molecule composed of monomers (amino acids) linearly linked by amide bonds (also known as peptide bonds). It indicates a molecular chain of amino acids and does not refer to a specific length of the product. Thus, peptides, dipeptides, tripeptides, oligopeptides and proteins are included within the definition of polypeptide. This term is also intended to refer to post-expression modifications of the polypeptide, for example, glycosolations, acetylations, phosphorylations, and the like. A recombinant or derived polypeptide is not necessarily translated from a designated nucleic acid sequence. It may also be generated in any manner, including chemical synthesis.

Residue: As used herein, the term “residue” is meant to mean a specific amino acid in a polypeptide backbone or side chain.

Self antigen: As used herein, the tem “self antigen” refers to proteins encoded by the host`s DNA and products generated by proteins or RNA encoded by the host`s DNA are defined as self. In addition, proteins that result from a combination of two

or several self-molecules or that represent a fraction of a self-molecule and proteins that have a high homology two self-molecules as defined above (>95%, preferably >97%, more preferably >99%) may also be considered self.

Treatment: As used herein, the terms "treatment", "treat", "treated" or "treating" refer to prophylaxis and/or therapy. When used with respect to an infectious disease, for example, the term refers to a prophylactic treatment which increases the resistance of a subject to infection with a pathogen or, in other words, decreases the likelihood that the subject will become infected with the pathogen or will show signs of illness attributable to the infection, as well as a treatment after the subject has become infected in order to fight the infection, *e.g.*, reduce or eliminate the infection or prevent it from becoming worse.

Vaccine: As used herein, the term "vaccine" refers to a formulation which contains the composition of the present invention and which is in a form that is capable of being administered to an animal. Typically, the vaccine comprises a conventional saline or buffered aqueous solution medium in which the composition of the present invention is suspended or dissolved. In this form, the composition of the present invention can be used conveniently to prevent, ameliorate, or otherwise treat a condition. Upon introduction into a host, the vaccine is able to provoke an immune response including, but not limited to, the production of antibodies and/or cytokines and/or the activation of cytotoxic T cells, antigen presenting cells, helper T cells, dendritic cells and/or other cellular responses.

Optionally, the vaccine of the present invention additionally includes an adjuvant which can be present in either a minor or major proportion relative to the compound of the present invention.

Virus-like particle (VLP): As used herein, the term "virus-like particle" refers to a structure resembling a virus particle. Moreover, a virus-like particle in accordance with the invention is non replicative and noninfectious since it lacks all or part of the viral genome, in particular the replicative and infectious components of the viral genome. A virus-like particle in accordance with the invention may contain nucleic acid distinct from their genome. A typical and preferred embodiment of a virus-like particle in accordance with the present invention is a viral capsid such as the viral capsid of the corresponding virus, bacteriophage, or RNA-phage. The terms

"viral capsid" or "capsid", as interchangeably used herein, refer to a macromolecular assembly composed of viral protein subunits. Typically and preferably, the viral protein subunits assemble into a viral capsid and capsid, respectively, having a structure with an inherent repetitive organization, wherein said structure is, typically, spherical or tubular. For example, the capsids of RNA-phages or HBcAg's have a spherical form of icosahedral symmetry. The term "capsid-like structure" as used herein, refers to a macromolecular assembly composed of viral protein subunits ressembling the capsid morphology in the above defined sense but deviating from the typical symmetrical assembly while maintaining a sufficient degree of order and repetitiveness.

Virus-like particle of a bacteriophage: As used herein, the term "virus-like particle of a bacteriophage" refers to a virus-like particle resembling the structure of a bacteriophage, being non replicative and noninfectious, and lacking at least the gene or genes encoding for the replication machinery of the bacteriophage, and typically also lacking the gene or genes encoding the protein or proteins responsible for viral attachment to or entry into the host. This definition should, however, also encompass virus-like particles of bacteriophages, in which the aforementioned gene or genes are still present but inactive, and, therefore, also leading to non-replicative and noninfectious virus-like particles of a bacteriophage.

VLP of RNA phage coat protein: The capsid structure formed from the self-assembly of 180 subunits of RNA phage coat protein and optionally containing host RNA is referred to as a "VLP of RNA phage coat protein". A specific example is the VLP of Qβ coat protein. In this particular case, the VLP of Qβ coat protein may either be assembled exclusively from Qβ CP subunits (generated by expression of a Qβ CP gene containing, for example, a TAA stop codon precluding any expression of the longer A1 protein through suppression, see Kozlovska, T.M., *et al.*, *Intervirology 39*: 9-15 (1996)), or additionally contain A1 protein subunits in the capsid assembly.

Virus particle: The term "virus particle" as used herein refers to the morphological form of a virus. In some virus types it comprises a genome surrounded by a protein capsid; others have additional structures (*e.g.*, envelopes, tails, etc.).

One, a, or an: When the terms "one," "a," or "an" are used in this disclosure, they mean "at least one" or "one or more," unless otherwise indicated.

As will be clear to those skilled in the art, certain embodiments of the invention involve the use of recombinant nucleic acid technologies such as cloning, polymerase chain reaction, the purification of DNA and RNA, the expression of recombinant proteins in prokaryotic and eukaryotic cells, etc. Such methodologies are well known to those skilled in the art and can be conveniently found in published laboratory methods manuals (*e.g.*, Sambrook, J. *et al.*, eds., *Molecular Cloning, A Laboratory Manual*, 2nd. edition, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y. (1989); Ausubel, F. *et al.*, eds., *Current Protocols in Molecular Biology*, John H. Wiley & Sons, Inc. (1997)). Fundamental laboratory techniques for working with tissue culture cell lines (Celis, J., ed., *Cell Biology*, Academic Press, 2nd edition, (1998)) and antibody-based technologies (Harlow, E. and Lane, D., *Antibodies: A Laboratory Manual*, Cold Spring Harbor Laboratory, Cold Spring Harbor, N.Y. (1988); Deutscher, M.P., "Guide to Protein Purification," *Meth. Enzymol. 128*, Academic Press San Diego (1990); Scopes, R.K., *Protein Purification Principles and Practice*, 3rd ed., Springer-Verlag, New York (1994)) are also adequately described in the literature, all of which are incorporated herein by reference.

2. Compositions and Methods for Enhancing an Immune Response

The disclosed invention provides compositions and methods for inducing an immune response against Aβ1-6 peptide in an animal, inducing antibodies capable of binding Aβ amyloid plaques and soluble Aβ. Compositions of the invention comprise, or alternatively consist of (a) a core particle with at least one first attachment site; and (b) at least one antigen or antigenic determinant with at least one second attachment site, wherein said antigen or antigenic determinant is an Aβ1-6 peptide, and wherein said second attachment site being selected from the group consisting of (i) an attachment site not naturally occurring with said antigen or antigenic determinant; and (ii) an attachment site naturally occurring with said antigen or antigenic determinant, wherein said second attachment site is capable of association to said first attachment site; and wherein said antigen or antigenic

determinant and said core particle interact through said association to form an ordered and repetitive antigen array. More specifically, compositions of the invention comprise, or alternatively consist of, a virus-like particle and at least one antigen or antigenic determinant, wherein the antigen or antigenic determinant is a Aβ1-6 peptide, and wherein the at least one antigen or antigenic determinant is bound to the virus-like particle so as to form an ordered and repetitive antigen-VLP-array. Furthermore, the invention conveniently enables the practitioner to construct such a composition, inter alia, for treatment and/or prophylactic prevention of Alzheimer's disease. Virus-like particles in the context of the present application refer to structures resembling a virus particle but which are not pathogenic. In general, virus-like particles lack the viral genome and, therefore, are noninfectious. Also, virus-like particles can be produced in large quantities by heterologous expression and can be easily purified.

In one embodiment, the core particle comprises, or is selected from a group consisting of, a virus, a bacterial pilus, a structure formed from bacterial pilin, a bacteriophage, a virus-like particle, a virus-like particle of a RNA phage, a viral capsid particle or a recombinant form thereof. Any virus known in the art having an ordered and repetitive coat and/or core protein structure may be selected as a core particle of the invention; examples of suitable viruses include sindbis and other alphaviruses, rhabdoviruses (*e.g.* vesicular stomatitis virus), picornaviruses (*e.g.*, human rhino virus, Aichi virus), togaviruses (*e.g.*, rubella virus), orthomyxoviruses (*e.g.*, Thogoto virus, Batken virus, fowl plague virus), polyomaviruses (*e.g.*, polyomavirus BK, polyomavirus JC, avian polyomavirus BFDV), parvoviruses, rotaviruses, Norwalk virus, foot and mouth disease virus, a retrovirus, Hepatitis B virus, Tobacco mosaic virus, Flock House Virus, and human Papilomavirus, and preferably a RNA phage, bacteriophage Qβ, bacteriophage R17, bacteriophage M11, bacteriophage MX1, bacteriophage NL95, bacteriophage fr, bacteriophage GA, bacteriophage SP, bacteriophage MS2, bacteriophage f2, bacteriophage PP7 (for example, *see* Table 1 in Bachmann, M.F. and Zinkernagel, R.M., *Immunol. Today* *17*:553-558 (1996)).

In a further embodiment, the invention utilizes genetic engineering of a virus to create a fusion between an ordered and repetitive viral envelope protein and a first

attachment site being comprised by, or alternatively or preferably being a heterologous protein, peptide, antigenic determinant or a reactive amino acid residue of choice. Other genetic manipulations known to those in the art may be included in the construction of the inventive compositions; for example, it may be desirable to restrict the replication ability of the recombinant virus through genetic mutation. Furthermore, the virus used for the present invention is replication incompetent due to chemical or physical inactivation or, as indicated, due to lack of a replication competent genome. The viral protein selected for fusion to the first attachment site should have an organized and repetitive structure. Such an organized and repetitive structure includes paracrystalline organizations with a spacing of 5-30 nm, preferably 5-15 nm, on the surface of the virus. The creation of this type of fusion protein will result in multiple, ordered and repetitive first attachment sites on the surface of the virus and reflect the normal organization of the native viral protein. As will be understood by those in the art, the first attachment site may be or be a part of any suitable protein, polypeptide, sugar, polynucleotide, peptide (amino acid), natural or synthetic polymer, a secondary metabolite or combination thereof that may serve to specifically attach the antigen or antigenic determinant leading an ordered and repetitive antigen array.

In another embodiment of the invention, the core particle is a recombinant alphavirus, and more specifically, a recombinant Sinbis virus. Alphaviruses are positive stranded RNA viruses that replicate their genomic RNA entirely in the cytoplasm of the infected cell and without a DNA intermediate (Strauss, J. and Strauss, E., *Microbiol. Rev. 58*:491-562 (1994)). Several members of the alphavirus family, Sindbis (Xiong, C. *et al., Science 243*:1188-1191 (1989); Schlesinger, S., *Trends Biotechnol. 11*:18-22 (1993)), Semliki Forest Virus (SFV) (Liljeström, P. & Garoff, H., *Bio/Technology 9*:1356-1361 (1991)) and others (Davis, N.L. *et al., Virology 171*:189-204 (1989)), have received considerable attention for use as virus-based expression vectors for a variety of different proteins (Lundstrom, K., *Curr. Opin. Biotechnol. 8*:578-582 (1997); Liljeström, P., *Curr. Opin. Biotechnol. 5*:495-500 (1994)) and as candidates for vaccine development. Recently, a number of patents have issued directed to the use of alphaviruses for the expression of heterologous proteins and the development of vaccines (*see* U.S. Patent Nos.

5,766,602; 5,792,462; 5,739,026; 5,789,245 and 5,814,482). The construction of the alphaviral core particles of the invention may be done by means generally known in the art of recombinant DNA technology, as described by the aforementioned articles, which are incorporated herein by reference.

A variety of different recombinant host cells can be utilized to produce a viral-based core particle for antigen or antigenic determinant attachment. For example, alphaviruses are known to have a wide host range; Sindbis virus infects cultured mammalian, reptilian, and amphibian cells, as well as some insect cells (Clark, H., *J. Natl. Cancer Inst. 51*:645 (1973); Leake, C., *J. Gen. Virol. 35*:335 (1977); Stollar, V. in THE TOGAVIRUSES, R.W. Schlesinger, Ed., Academic Press, (1980), pp.583-621). Thus, numerous recombinant host cells can be used in the practice of the invention. BHK, COS, Vero, HeLa and CHO cells are particularly suitable for the production of heterologous proteins because they have the potential to glycosylate heterologous proteins in a manner similar to human cells (Watson, E. *et al., Glycobiology 4*:227, (1994)) and can be selected (Zang, M. *et al., Bio/Technology 13*:389 (1995)) or genetically engineered (Renner W. *et al., Biotech. Bioeng. 4*:476 (1995); Lee K. *et al. Biotech. Bioeng. 50*:336 (1996)) to grow in serum-free medium, as well as in suspension.

Introduction of the polynucleotide vectors into host cells can be effected by methods described in standard laboratory manuals (*see, e.g.*, Sambrook, J. *et al.*, eds., MOLECULAR CLONING, A LABORATORY MANUAL, 2nd. edition, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y. (1989), Chapter 9; Ausubel, F. *et al.*, eds., CURRENT PROTOCOLS IN MOLECULAR BIOLOGY, John H. Wiley & Sons, Inc. (1997), Chapter 16), including methods such as electroporation, DEAE-dextran mediated transfection, transfection, microinjection, cationic lipid-mediated transfection, transduction, scrape loading, ballistic introduction, and infection. Methods for the introduction of exogenous DNA sequences into host cells are discussed in Felgner, P. *et al.*, U.S. Patent No. 5,580,859.

Packaged RNA sequences can also be used to infect host cells. These packaged RNA sequences can be introduced to host cells by adding them to the culture medium. For example, the preparation of non-infective alpahviral particles is

described in a number of sources, including "Sindbis Expression System", Version C (*Invitrogen* Catalog No. K750-1).

When mammalian cells are used as recombinant host cells for the production of viral-based core particles, these cells will generally be grown in tissue culture. Methods for growing cells in culture are well known in the art (*see, e.g.*, Celis, J., ed., CELL BIOLOGY, Academic Press, 2nd edition, (1998); Sambrook, J. *et al.*, eds., MOLECULAR CLONING, A LABORATORY MANUAL, 2nd. edition, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y. (1989); Ausubel, F. *et al.*, eds., CURRENT PROTOCOLS IN MOLECULAR BIOLOGY, John H. Wiley & Sons, Inc. (1997); Freshney, R., CULTURE OF ANIMAL CELLS, Alan R. Liss, Inc. (1983)).

Further examples of RNA viruses suitable for use as core particle in the present invention include, but are not limited to, the following: members of the family Reoviridae, including the genus Orthoreovirus (multiple serotypes of both mammalian and avian retroviruses), the genus Orbivirus (Bluetongue virus, Eugenangee virus, Kemerovo virus, African horse sickness virus, and Colorado Tick Fever virus), the genus Rotavirus (human rotavirus, Nebraska calf diarrhea virus, murine rotavirus, simian rotavirus, bovine or ovine rotavirus, avian rotavirus); the family Picomaviridae, including the genus Enterovirus (poliovirus, Coxsackie virus A and B, enteric cytopathic human orphan (ECHO) viruses, hepatitis A, C, D, E and G viruses, Simian enteroviruses, Murine encephalomyelitis (ME) viruses, Poliovirus muris, Bovine enteroviruses, Porcine enteroviruses, the genus Cardiovirus (Encephalomyocarditis virus (EMC), Mengovirus), the genus Rhinovirus (Human rhinoviruses including at least 113 subtypes; other rhinoviruses), the genus Apthovirus (Foot and Mouth disease (FMDV); the family Calciviridae, including Vesicular exanthema of swine virus, San Miguel sea lion virus, Feline picornavirus and Norwalk virus; the family Togaviridae, including the genus Alphavirus (Eastern equine encephalitis virus, Semliki forest virus, Sindbis virus, Chikungunya virus, O'Nyong-Nyong virus, Ross river virus, Venezuelan equine encephalitis virus, Western equine encephalitis virus), the genus Flavirius (Mosquito borne yellow fever virus, Dengue virus, Japanese encephalitis virus, St. Louis encephalitis virus, Murray Valley encephalitis virus, West Nile virus, Kunjin virus, Central European tick borne virus, Far Eastern tick borne virus, Kyasanur forest virus, Louping III virus,

Powassan virus, Omsk hemorrhagic fever virus), the genus Rubivirus (Rubella virus), the genus Pestivirus (Mucosal disease virus, Hog cholera virus, Border disease virus); the family Bunyaviridae, including the genus Bunyvirus (Bunyamwera and related viruses, California encephalitis group viruses), the genus Phlebovirus (Sandfly fever Sicilian virus, Rift Valley fever virus), the genus Nairovirus (Crimean-Congo hemorrhagic fever virus, Nairobi sheep disease virus), and the genus Uukuvirus (Uukuniemi and related viruses); the family Orthomyxoviridae, including the genus Influenza virus (Influenza virus type A, many human subtypes); Swine influenza virus, and Avian and Equine Influenza viruses; influenza type B (many human subtypes), and influenza type C (possible separate genus); the family paramyxoviridae, including the genus Paramyxovirus (Parainfluenza virus type 1, Sendai virus, Hemadsorption virus, Parainfluenza viruses types 2 to 5, Newcastle Disease Virus, Mumps virus), the genus Morbillivirus (Measles virus, subacute sclerosing panencephalitis virus, distemper virus, Rinderpest *virus*), the genus Pneumovirus (respiratory syncytial virus (RSV), Bovine respiratory syncytial virus and Pneumonia virus of mice); forest virus, Sindbis virus, Chikungunya virus, O'Nyong-Nyong virus, Ross river virus, Venezuelan equine encephalitis virus, Western equine encephalitis virus), the genus Flavirius (Mosquito borne yellow fever virus, Dengue virus, Japanese encephalitis virus, St. Louis encephalitis virus, Murray Valley encephalitis virus, West Nile virus, Kunjin virus, Central European tick borne virus, Far Eastern tick borne virus, Kyasanur forest virus, Louping III virus, Powassan virus, Omsk hemorrhagic fever virus), the genus Rubivirus (Rubella virus), the genus Pestivirus (Mucosal disease virus, Hog cholera virus, Border disease virus); the family Bunyaviridae, including the genus Bunyvirus (Bunyamwera and related viruses, California encephalitis group viruses), the genus Phlebovirus (Sandfly fever Sicilian virus, Rift Valley fever virus), the genus Nairovirus (Crimean-Congo hemorrhagic fever virus, Nairobi sheep disease virus), and the genus Uukuvirus (Uukuniemi and related viruses); the family Orthomyxoviridae, including the genus Influenza virus (Influenza virus type A, many human subtypes); Swine influenza virus, and Avian and Equine Influenza viruses; influenza type B (many human subtypes), and influenza type C (possible separate genus); the family paramyxoviridae, including the genus Paramyxovirus

(Parainfluenza virus type 1, Sendai virus, Hemadsorption virus, Parainfluenza viruses types 2 to 5, Newcastle Disease Virus, Mumps virus), the genus Morbillivirus (Measles virus, subacute sclerosing panencephalitis virus, distemper virus, Rinderpest virus), the genus Pneumovirus (respiratory syncytial virus (RSV), Bovine respiratory syncytial *virus* and Pneumonia virus of mice); the family Rhabdoviridae, including the genus Vesiculovirus (VSV), Chandipura virus, Flanders-Hart Park virus), the genus Lyssavirus (Rabies virus), fish Rhabdoviruses and, filoviruses (Marburg virus and Ebola virus); the family Arenaviridae, including Lymphocytic choriomeningitis virus (LCM), Tacaribe virus complex, and Lassa virus; the family Coronoaviridae, including Infectious Bronchitis Virus (IBV), Mouse Hepatitis virus, Human enteric corona virus, and Feline infectious peritonitis (Feline coronavirus).

Illustrative DNA viruses that may be used as core particle include, but are not limited to: the family Poxviridae, including the genus Orthopoxvirus (Variola major, Variola minor, Monkey pox Vaccinia, Cowpox, Buffalopox, Rabbitpox, Ectromelia), the genus Leporipoxvirus (Myxoma, Fibroma), the genus Avipoxvirus (Fowlpox, other avian poxvirus), the genus Capripoxvirus (sheeppox, goatpox), the genus Suipoxvirus (Swinepox), the genus Parapoxvirus (contagious postular dermatitis virus, pseudocowpox, bovine papular stomatitis virus); the family Iridoviridae (African swine fever virus, Frog viruses 2 and 3, Lymphocystis virus of fish); the family Herpesviridae, including the alpha-Herpesviruses (Herpes Simplex Types 1 and 2, Varicella-Zoster, Equine abortion virus, Equine herpes virus 2 and 3, pseudorabies virus, infectious bovine keratoconjunctivitis virus, infectious bovine rhinotracheitis virus, feline rhinotracheitis virus, infectious laryngotracheitis virus) the Beta-herpesviruses (Human cytomegalovirus and cytomegaloviruses of swine, monkeys and rodents); the gamma-herpesviruses (Epstein-Barr virus (EBV), Marek's disease virus, Herpes saimiri, Herpesvirus ateles, Herpesvirus sylvilagus, guinea pig herpes virus, Lucke tumor virus); the family Adenoviridae, including the genus Mastadenovirus (Human subgroups A, B, C, D and E and ungrouped; simian adenoviruses (at least 23 serotypes), infectious canine hepatitis, and adenoviruses of cattle, pigs, sheep, frogs and many other species, the genus Aviadenovirus (Avian adenoviruses); and non-cultivatable adenoviruses; the family Papoviridae, including the genus Papillomavirus (Human papilloma viruses, bovine papilloma viruses,

Shope rabbit papilloma virus, and various pathogenic papilloma viruses of other species), the genus Polyomavirus (polyomavirus, Simian vacuolating agent (SV-40), Rabbit vacuolating agent (RKV), K virus, BK virus, JC virus, and other primate polyoma viruses such as Lymphotrophic papilloma virus); the family Parvoviridae including the genus Adeno-associated viruses, the genus Parvovirus (Feline panleukopenia virus, bovine parvovirus, canine parvovirus, Aleutian mink disease virus, etc.). Finally, DNA viruses may include viruses such as chronic infectious neuropathic agents (CHINA virus).

In other embodiments, a bacterial pilin, a subportion of a bacterial pilin, or a fusion protein which contains either a bacterial pilin or subportion thereof is used to prepare compositions and vaccine compositions, respectively, of the invention. Examples of pilin proteins include pilins produced by *Escherichia coli*, *Haemophilus influenzae*, *Neisseria meningitidis*, *Neisseria gonorrhoeae*, *Caulobacter crescentus*, *Pseudomonas stutzeri*, and *Pseudomonas aeruginosa*. The amino acid sequences of pilin proteins suitable for use with the present invention include those set out in GenBank reports AJ000636, AJ132364, AF229646, AF051814, AF051815, and X00981, the entire disclosures of which are incorporated herein by reference.

Bacterial pilin proteins are generally processed to remove N-terminal leader sequences prior to export of the proteins into the bacterial periplasm. Further, as one skilled in the art would recognize, bacterial pilin proteins used to prepare compositions and vaccine compositions, respectively, of the invention will generally not have the naturally present leader sequence.

One specific example of a pilin protein suitable for use in the present invention is the P-pilin of *E. coli* (GenBank report AF237482 (SEQ ID NO:1)). An example of a Type-1 *E. coli* pilin suitable for use with the invention is a pilin having the amino acid sequence set out in GenBank report P04128 (SEQ ID NO:2), which is encoded by nucleic acid having the nucleotide sequence set out in GenBank report M27603 (SEQ ID NO:3). The entire disclosures of these GenBank reports are incorporated herein by reference. Again, the mature form of the above referenced protein would generally be used to prepare compositions and vaccine compositions, respectively, of the invention.

Bacterial pilins or pilin subportions suitable for use in the practice of the present invention will generally be able to associate to form ordered and repetitive antigen arrays.

Methods for preparing pili and pilus-like structures *in vitro* are known in the art. Bullitt *et al., Proc. Natl. Acad. Sci. USA 93*:12890-12895 (1996), for example, describe the *in vitro* reconstitution of *E. coli* P-pili subunits. Furthermore, Eshdat *et al., J. Bacteriol. 148*:308-314 (1981) describe methods suitable for dissociating Type-1 pili of *E. coli* and the reconstitution of pili. In brief, these methods are as follows: pili are dissociated by incubation at 37°C in saturated guanidine hydrochloride. Pilin proteins are then purified by chromatography, after which pilin dimers are formed by dialysis against 5 mM tris(hydroxymethyl) aminomethane hydrochloride (pH 8.0). Eshdat *et al.* also found that pilin dimers reassemble to form pili upon dialysis against the 5 mM tris(hydroxymethyl) aminomethane (pH 8.0) containing 5 mM $MgCl_2$.

Further, using, for example, conventional genetic engineering and protein modification methods, pilin proteins may be modified to contain a first attachment site to which an antigen or antigenic determinant is linked through a second attachment site. Alternatively, antigens or antigenic determinants can be directly linked through a second attachment site to amino acid residues which are naturally resident in these proteins. These modified pilin proteins may then be used in vaccine compositions of the invention.

Bacterial pilin proteins used to prepare compositions and vaccine compositions, respectively, of the invention may be modified in a manner similar to that described herein for HBcAg. For example, cysteine and lysine residues may be either deleted or substituted with other amino acid residues and first attachment sites may be added to these proteins. Further, pilin proteins may either be expressed in modified form or may be chemically modified after expression. Similarly, intact pili may be harvested from bacteria and then modified chemically.

In another embodiment, pili or pilus-like structures are harvested from bacteria (*e.g., E. coli*) and used to form compositions and vaccine compositions of the invention. One example of pili suitable for preparing compositions and vaccine

compositions is the Type-1 pilus of *E. coli*, which is formed from pilin monomers having the amino acid sequence set out in SEQ ID NO:2.

A number of methods for harvesting bacterial pili are known in the art. Bullitt and Makowski (*Biophys. J. 74*:623-632 (1998)), for example, describe a pilus purification method for harvesting P-pili from *E. coli*. According to this method, pili are sheared from hyperpiliated *E. coli* containing a P-pilus plasmid and purified by cycles of solubilization and $MgCl_2$ (1.0 M) precipitation.

Once harvested, pili or pilus-like structures may be modified in a variety of ways. For example, a first attachment site can be added to the pili to which antigens or antigen determinants may be attached through a second attachment site. In other words, bacterial pili or pilus-like structures can be harvested and modified to lead to ordered and repetitive antigen arrays.

Antigens or antigenic determinants could be linked to naturally occurring cysteine resides or lysine residues present in Pili or pilus-like structures. In such instances, the high order and repetitiveness of a naturally occurring amino acid residue would guide the coupling of the antigens or antigenic determinants to the pili or pilus-like structures. For example, the pili or pilus-like structures could be linked to the second attachment sites of the antigens or antigenic determinants using a heterobifunctional cross-linking agent.

When structures which are naturally synthesized by organisms (*e.g.*, pili) are used to prepare compositions and vaccine compositions of the invention, it will often be advantageous to genetically engineer these organisms so that they produce structures having desirable characteristics. For example, when Type-1 pili of *E. coli* are used, the *E. coli* from which these pili are harvested may be modified so as to produce structures with specific characteristics. Examples of possible modifications of pilin proteins include the insertion of one or more lysine residues, the deletion or substitution of one or more of the naturally resident lysine residues, and the deletion or substitution of one or more naturally resident cysteine residues (*e.g.*, the cysteine residues at positions 44 and 84 in SEQ ID NO:2).

Further, additional modifications can be made to pilin genes which result in the expression products containing a first attachment site other than a lysine residue (*e.g.*, a *FOS* or *JUN* domain). Of course, suitable first attachment sites will generally

be limited to those which do not prevent pilin proteins from forming pili or pilus-like structures suitable for use in vaccine compositions of the invention.

Pilin genes which naturally reside in bacterial cells can be modified *in vivo* (*e.g.*, by homologous recombination) or pilin genes with particular characteristics can be inserted into these cells. For examples, pilin genes could be introduced into bacterial cells as a component of either a replicable cloning vector or a vector which inserts into the bacterial chromosome. The inserted pilin genes may also be linked to expression regulatory control sequences (*e.g.*, a *lac* operator).

In most instances, the pili or pilus-like structures used in compositions and vaccine compositions, respectively, of the invention will be composed of single type of a pilin subunit. Pili or pilus-like structures composed of identical subunits will generally be used because they are expected to form structures which present highly ordered and repetitive antigen arrays.

However, the compositions of the invention also include compositions and vaccines comprising pili or pilus-like structures formed from heterogenous pilin subunits. The pilin subunits which form these pili or pilus-like structures can be expressed from genes naturally resident in the bacterial cell or may be introduced into the cells. When a naturally resident pilin gene and an introduced gene are both expressed in a cell which forms pili or pilus-like structures, the result will generally be structures formed from a mixture of these pilin proteins. Further, when two or more pilin genes are expressed in a bacterial cell, the relative expression of each pilin gene will typically be the factor which determines the ratio of the different pilin subunits in the pili or pilus-like structures.

When pili or pilus-like structures having a particular composition of mixed pilin subunits is desired, the expression of at least one of the pilin genes can be regulated by a heterologous, inducible promoter. Such promoters, as well as other genetic elements, can be used to regulate the relative amounts of different pilin subunits produced in the bacterial cell and, hence, the composition of the pili or pilus-like structures.

In additional, the antigen or antigenic determinant can be linked to bacterial pili or pilus-like structures by a bond which is not a peptide bond, bacterial cells which produce pili or pilus-like structures used in the compositions of the invention

can be genetically engineered to generate pilin proteins which are fused to an antigen or antigenic determinant. Such fusion proteins which form pili or pilus-like structures are suitable for use in vaccine compositions of the invention.

In a preferred embodiment, the core particle is a virus-like particle, wherein the virus-like particle is a recombinant virus-like particle. The skilled artisan can produce VLPs using recombinant DNA technology and virus coding sequences which are readily available to the public. For example, the coding sequence of a virus envelope or core protein can be engineered for expression in a baculovirus expression vector using a commercially available baculovirus vector, under the regulatory control of a virus promoter, with appropriate modifications of the sequence to allow functional linkage of the coding sequence to the regulatory sequence. The coding sequence of a virus envelope or core protein can also be engineered for expression in a bacterial expression vector, for example.

Examples of VLPs include, but are not limited to, the capsid proteins of Hepatitis B virus (Ulrich, *et al.*, *Virus Res. 50*:141-182 (1998)), measles virus (Warnes, *et al., Gene 160*:173-178 (1995)), Sindbis virus, rotavirus (US 5,071,651 and US 5,374,426), foot-and-mouth-disease virus (Twomey, *et al., Vaccine 13*:1603-1610, (1995)), Norwalk virus (Jiang, X., *et al., Science 250*:1580-1583 (1990); Matsui, S.M., *et al., J. Clin. Invest. 87*:1456-1461 (1991)), the retroviral GAG protein (WO 96/30523), the retrotransposon Ty protein p1, the surface protein of Hepatitis B virus (WO 92/11291), human papilloma virus (WO 98/15631), RNA phages, Ty, fr-phage, GA-phage, AP205-phage and Qβ-phage.

As will be readily apparent to those skilled in the art, the VLP of the invention is not limited to any specific form. The particle can be synthesized chemically or through a biological process, which can be natural or non-natural. By way of example, this type of embodiment includes a virus-like particle or a recombinant form thereof.

In a more specific embodiment, the VLP can comprise, or alternatively essentially consist of, or alternatively consist of recombinant polypeptides, or fragments thereof, being selected from recombinant polypeptides of Rotavirus, recombinant polypeptides of Norwalk virus, recombinant polypeptides of Alphavirus, recombinant polypeptides of Foot and Mouth Disease virus, recombinant

polypeptides of measles virus, recombinant polypeptides of Sindbis virus, recombinant polypeptides of Polyoma virus, recombinant polypeptides of Retrovirus, recombinant polypeptides of Hepatitis B virus (*e.g.*, a HBcAg), recombinant polypeptides of Tobacco mosaic virus, recombinant polypeptides of Flock House Virus, recombinant polypeptides of human Papillomavirus, recombinant polypeptides of bacteriophages, recombinant polypeptides of RNA phages, recombinant polypeptides of Ty, recombinant polypeptides of fr-phage, recombinant polypeptides of GA-phage and recombinant polypeptides of Qβ-phage. The virus-like particle can further comprise, or alternatively essentially consist of, or alternatively consist of, one or more fragments of such polypeptides, as well as variants of such polypeptides. Variants of polypeptides can share, for example, at least 80%, 85%, 90%, 95%, 97%, or 99% identity at the amino acid level with their wild-type counterparts.

In a preferred embodiment, the virus-like particle comprises, consists essentially of, or alternatively consists of recombinant proteins, or fragments thereof, of a RNA-phage. Preferably, the RNA-phage is selected from the group consisting of a) bacteriophage Qβ; b) bacteriophage R17; c) bacteriophage fr; d) bacteriophage GA; e) bacteriophage SP; f) bacteriophage MS2; g) bacteriophage M11; h) bacteriophage MX1; i) bacteriophage NL95; k) bacteriophage f2; l) bacteriophage PP7, and m) bacteriophage AP205.

In another preferred embodiment of the present invention, the virus-like particle comprises, or alternatively consists essentially of, or alternatively consists of recombinant proteins, or fragments thereof, of the RNA-bacteriophage Qβ or of the RNA-bacteriophage fr, or of the RNA-bacteriophage AP205.

In a further preferred embodiment of the present invention, the recombinant proteins comprise, or alternatively consist essentially of, or alternatively consist of coat proteins of RNA phages.

RNA-phage coat proteins forming capsids or VLPs, or fragments of the bacteriophage coat proteins compatible with self-assembly into a capsid or a VLP, are, therefore, further preferred embodiments of the present invention. Bacteriophage Qβ coat proteins, for example, can be expressed recombinantly in *E.*

coli. Further, upon such expression these proteins spontaneously form capsids. Additionally, these capsids form a structure with an inherent repetitive organization.

Specific preferred examples of bacteriophage coat proteins which can be used to prepare compositions of the invention include the coat proteins of RNA bacteriophages such as bacteriophage Qβ (SEQ ID NO:4; PIR Database, Accession No. VCBPQβ referring to Qβ CP and SEQ ID NO: 5; Accession No. AAA16663 referring to Qβ A1 protein), bacteriophage R17 (SEQ ID NO:6; PIR Accession No. VCBPR7), bacteriophage fr (SEQ ID NO:7; PIR Accession No. VCBPFR), bacteriophage GA (SEQ ID NO:8; GenBank Accession No. NP-040754), bacteriophage SP (SEQ ID NO:9; GenBank Accession No. CAA30374 referring to SP CP and SEQ ID NO: 10; Accession No. NP 695026 referring to SP A1 protein), bacteriophage MS2 (SEQ ID NO:11; PIR Accession No. VCBPM2), bacteriophage M11 (SEQ ID NO:12; GenBank Accession No. AAC06250), bacteriophage MX1 (SEQ ID NO:13; GenBank Accession No. AAC14699), bacteriophage NL95 (SEQ ID NO:14; GenBank Accession No. AAC14704), bacteriophage f2 (SEQ ID NO: 15; GenBank Accession No. P03611), bacteriophage PP7 (SEQ ID NO: 16), and bacteriophage AP205 (SEQ ID NO: 28). Furthermore, the A1 protein of bacteriophage Qβ (SEQ ID NO: 5) or C-terminal truncated forms missing as much as 100, 150 or 180 amino acids from its C-terminus may be incorporated in a capsid assembly of Qβ coat proteins. Generally, the percentage of Qβ A1 protein relative to Qβ CP in the capsid assembly will be limited, in order to ensure capsid formation.

Qβ coat protein has also been found to self-assemble into capsids when expressed in *E. coli* (Kozlovska TM. *et al., GENE 137*: 133-137 (1993)). The obtained capsids or virus-like particles showed an icosahedral phage-like capsid structure with a diameter of 25 nm and T=3 quasi symmetry. Further, the crystal structure of phage Qβ has been solved. The capsid contains 180 copies of the coat protein, which are linked in covalent pentamers and hexamers by disulfide bridges (Golmohammadi, R. *et al., Structure 4*: 543-5554 (1996)) leading to a remarkable stability of the capsid of Qβ coat protein. Capsids or VLPs made from recombinant Qβ coat protein may contain, however, subunits not linked via disulfide links to other subunits within the capsid, or incompletely linked. However, typically more than about 80% of the subunits are linked via disulfide bridges to each other within the

VLP. Thus, upon loading recombinant Qβ capsid on non-reducing SDS-PAGE, bands corresponding to monomeric Qβ coat protein as well as bands corresponding to the hexamer or pentamer of Qβ coat protein are visible. Incompletely disulfide-linked subunits could appear as dimer, trimer or even tetramer bands in non-reducing SDS-PAGE. Qβ capsid protein also shows unusual resistance to organic solvents and denaturing agents. Surprisingly, we have observed that DMSO and acetonitrile concentrations as high as 30%, and Guanidinium concentrations as high as 1 M do not affect the stability of the capsid. The high stability of the capsid of Qβ coat protein is an advantageous feature, in particular, for its use in immunization and vaccination of mammals and humans in accordance of the present invention.

Upon expression in *E. coli*, the N-terminal methionine of Qβ coat protein is usually removed, as we observed by N-terminal Edman sequencing as described in Stoll, E. et al. J. Biol. Chem. 252:990-993 (1977). VLP composed from Qβ coat proteins where the N-terminal methionine has not been removed, or VLPs comprising a mixture of Qβ coat proteins where the N-terminal methionine is either cleaved or present are also within the scope of the present invention.

Further preferred virus-like particles of RNA-phages, in particular of Qβ, in accordance of this invention are disclosed in WO 02/056905, the disclosure of which is herewith incorporated by reference in its entirety.

Further RNA phage coat proteins have also been shown to self-assemble upon expression in a bacterial host (Kastelein, RA. *et al., Gene 23*: 245-254 (1983), Kozlovskaya, TM. *et al., Dokl. Akad. Nauk SSSR 287*: 452-455 (1986), Adhin, MR. *et al., Virology 170*: 238-242 (1989), Ni, CZ., *et al., Protein Sci. 5*: 2485-2493 (1996), Priano, C. et al., J. Mol. Biol. 249: 283-297 (1995)). The Qβ phage capsid contains, in addition to the coat protein, the so called read-through protein A1 and the maturation protein A2. A1 is generated by suppression at the UGA stop codon and has a length of 329 aa. The capsid of phage Qβ recombinant coat protein used in the invention is devoid of the A2 lysis protein, and contains RNA from the host. The coat protein of RNA phages is an RNA binding protein, and interacts with the stem loop of the ribosomal binding site of the replicase gene acting as a translational repressor during the life cycle of the virus. The sequence and structural elements of the interaction are known (Witherell, GW. & Uhlenbeck, OC. *Biochemistry 28*: 71-

76 (1989); Lim F. et al., *J. Biol. Chem. 271*: 31839-31845 (1996)). The stem loop and RNA in general are known to be involved in the virus assembly (Golmohammadi, R. *et al., Structure 4*: 543-5554 (1996)).

In a further preferred embodiment of the present invention, the virus-like particle comprises, or alternatively consists essentially of, or alternatively consists of recombinant proteins, or fragments thereof, of a RNA-phage, wherein the recombinant proteins comprise, alternatively consist essentially of or alternatively consist of mutant coat proteins of a RNA phage, preferably of mutant coat proteins of the RNA phages mentioned above. In another preferred embodiment, the mutant coat proteins of the RNA phage have been modified by removal of at least one, or alternatively at least two, lysine residue by way of substitution, or by addition of at least one lysine residue by way of substitution; alternatively, the mutant coat proteins of the RNA phage have been modified by deletion of at least one, or alternatively at least two, lysine residue, or by addition of at least one lysine residue by way of insertion. The deletion, substitution or addition of at least one lysine residue allows varying the degree of coupling, i.e. the amount of Aβ1-6 peptides per subunits of theVLP of the RNA-phages, in particular, to match and tailor the requirements of the vaccine.

In another preferred embodiment, the virus-like particle comprises, or alternatively consists essentially of, or alternatively consists of recombinant proteins, or fragments thereof, of the RNA-bacteriophage Qβ, wherein the recombinant proteins comprise, or alternatively consist essentially of, or alternatively consist of coat proteins having an amino acid sequence of SEQ ID NO:4, or a mixture of coat proteins having amino acid sequences of SEQ ID NO:4 and of SEQ ID NO: 5 or mutants of SEQ ID NO: 5 and wherein the N-terminal methionine is preferably cleaved.

In a further preferred embodiment of the present invention, the virus-like particle comprises, consists essentially of or alternatively consists of recombinant proteins of Qβ, or fragments thereof, wherein the recombinant proteins comprise, or alternatively consist essentially of, or alternatively consist of mutant Qβ coat proteins. In another preferred embodiment, these mutant coat proteins have been modified by removal of at least one lysine residue by way of substitution, or by

addition of at least one lysine residue by way of substitution. Alternatively, these mutant coat proteins have been modified by deletion of at least one lysine residue, or by addition of at least one lysine residue by way of insertion.

Four lysine residues are exposed on the surface of the capsid of Qβ coat protein. Qβ mutants, for which exposed lysine residues are replaced by arginines can also be used for the present invention. The following Qβ coat protein mutants and mutant Qβ VLPs can, thus, be used in the practice of the invention: "Qβ-240" (Lys13-Arg; SEQ ID NO:17), "Qβ-243" (Asn 10-Lys; SEQ ID NO:18), "Qβ-250" (Lys 2-Arg, Lys13-Arg; SEQ ID NO:19), "Qβ-251" (SEQ ID NO:20) and "Qβ-259" (Lys 2-Arg, Lys16-Arg; SEQ ID NO:21). Thus, in further preferred embodiment of the present invention, the virus-like particle comprises, consists essentially of or alternatively consists of recombinant proteins of mutant Qβ coat proteins, which comprise proteins having an amino acid sequence selected from the group of a) the amino acid sequence of SEQ ID NO: 17; b) the amino acid sequence of SEQ ID NO:18; c) the amino acid sequence of SEQ ID NO: 19; d) the amino acid sequence of SEQ ID NO:20; and e) the amino acid sequence of SEQ ID NO: 21. The construction, expression and purification of the above indicated Qβ coat proteins, mutant Qβ coat protein VLPs and capsids, respectively, are described in WO 02/056905. In particular is hereby referred to Example 18 of above mentioned application.

In a further preferred embodiment of the present invention, the virus-like particle comprises, or alternatively consists essentially of, or alternatively consists of recombinant proteins of Qβ, or fragments thereof, wherein the recombinant proteins comprise, consist essentially of or alternatively consist of a mixture of either one of the foregoing Qβ mutants and the corresponding A1 protein.

In a further preferred embodiment of the present invention, the virus-like particle comprises, or alternatively essentially consists of, or alternatively consists of recombinant proteins, or fragments thereof, of RNA-phage AP205.

The AP205 genome consists of a maturation protein, a coat protein, a replicase and two open reading frames not present in related phages; a lysis gene and an open reading frame playing a role in the translation of the maturation gene (Klovins,J., *et al., J. Gen. Virol. 83*: 1523-33 (2002)). AP205 coat protein can be expressed from

plasmid pAP283-58 (SEQ ID NO: 27), which is a derivative of pQb10 (Kozlovska, T. M.. *et al.*, *Gene 137*:133-37 (1993)), and which contains an AP205 ribosomal binding site. Alternatively, AP205 coat protein may be cloned into pQb185, downstream of the ribosomal binding site present in the vector. Both approaches lead to expression of the protein and formation of capsids as described in the co-pending US provisional patent application with the title "Molecular Antigen Arrays" (Atty. Docket No. 1700.0310000) and having been filed on July 17, 2002, which is incorporated by reference in its entirety. Vectors pQb10 and pQb185 are vectors derived from pGEM vector, and expression of the cloned genes in these vectors is controlled by the *trp* promoter (Kozlovska, T. M. *et al.*, *Gene 137*:133-37 (1993)). Plasmid pAP283-58 (SEQ ID NO:27) comprises a putative AP205 ribosomal binding site in the following sequence, which is downstream of the XbaI site, and immediately upstream of the ATG start codon of the AP205 coat protein: *tctaga*ATTTTCTGCGCACCCAT CCCGGGTGGCGCCCAAAGTGAGGAAAATCAC*atg* (SEQ ID NO:57). The vector pQb185 comprises a Shine Delagarno sequence downstream from the XbaI site and upstream of the start codon (*tctaga*TTAACCCAACGCGTAGGAG TCAGGCC*atg* (SEQ ID NO:58), Shine Delagarno sequence underlined).

In a further preferred embodiment of the present invention, the virus-like particle comprises, or alternatively essentially consists of, or alternatively consists of recombinant coat proteins, or fragments thereof, of the RNA-phage AP205.

This preferred embodiment of the present invention, thus, comprises AP205 coat proteins that form capsids. Such proteins are recombinantly expressed, or prepared from natural sources. AP205 coat proteins produced in bacteria spontaneously form capsids, as evidenced by Electron Microscopy (EM) and immunodiffusion. The structural properties of the capsid formed by the AP205 coat protein (SEQ ID NO: 28) and those formed by the coat protein of the AP205 RNA phage are nearly indistinguishable when seen in EM. AP205 VLPs are highly immunogenic, and can be linked with antigens and/or antigenic determinants to generate vaccine constructs displaying the antigens and/or antigenic determinants oriented in a repetitive manner. High titers are elicited against the so displayed

antigens showing that bound antigens and/or antigenic determinants are accessible for interacting with antibody molecules and are immunogenic.

In a further preferred embodiment of the present invention, the virus-like particle comprises, or alternatively essentially consists of, or alternatively consists of recombinant mutant coat proteins, or fragments thereof, of the RNA-phage AP205.

Assembly-competent mutant forms of AP205 VLPs, including AP205 coat protein with the subsitution of proline at amino acid 5 to threonine (SEQ ID NO: 29), may also be used in the practice of the invention and leads to a further preferred embodiment of the invention. These VLPs, AP205 VLPs derived from natural sources, or AP205 viral particles, may be bound to antigens to produce ordered repetitive arrays of the antigens in accordance with the present invention.

AP205 P5-T mutant coat protein can be expressed from plasmid pAP281-32 (SEQ ID No. 30), which is derived directly from pQb185, and which contains the mutant AP205 coat protein gene instead of the Qβ coat protein gene. Vectors for expression of the AP205 coat protein are transfected into *E. coli* for expression of the AP205 coat protein.

Methods for expression of the coat protein and the mutant coat protein, respectively, leading to the self-assembly into VLPs are described in Example 1. Suitable *E. coli* strains include, but are not limited to, *E. coli* K802, JM 109, RR1. Suitable vectors and strains and combinations thereof can be identified by testing expression of the coat protein and mutant coat protein, respectively, by SDS-PAGE and capsid formation and assembly by optionally first purifying the capsids by gel filtration and subsequently testing them in an immunodiffusion assay (Ouchterlony test) or Electron Microscopy (Kozlovska, T. M.. *et al.*, *Gene 137*:133-37 (1993)).

AP205 coat proteins expressed from the vectors pAP283-58 and pAP281-32 may be devoid of the initial Methionine amino-acid, due to processing in the cytoplasm of *E. coli*. Cleaved, uncleaved forms of AP205 VLP or mixtures thereof are further preferred embodiments of the invention.

In a further preferred embodiment of the present invention, the virus-like particle comprises, or alternatively essentially consists of, or alternatively consists of a mixture of recombinant coat proteins, or fragments thereof, of the RNA-phage

AP205 and of recombinant mutant coat proteins, or fragments thereof, of the RNA-phage AP205.

In a further preferred embodiment of the present invention, the virus-like particle comprises, or alternatively essentially consists of, or alternatively consists of fragments of recombinant coat proteins or recombinant mutant coat proteins of the RNA-phage AP205.

Recombinant AP205 coat protein fragments capable of assembling into a VLP and a capsid, respectively are also useful in the practice of the invention. These fragments may be generated by deletion, either internally or at the termini of the coat protein and mutant coat protein, respectively. Insertions in the coat protein and mutant coat protein sequence or fusions of antigen sequences to the coat protein and mutant coat protein sequence, and compatible with assembly into a VLP, are further embodiments of the invention and lead to chimeric AP205 coat proteins, and particles, respectively. The outcome of insertions, deletions and fusions to the coat protein sequence and whether it is compatible with assembly into a VLP can be determined by electron microscopy.

The particles formed by the AP205 coat protein, coat protein fragments and chimeric coat proteins described above, can be isolated in pure form by a combination of fractionation steps by precipitation and of purification steps by gel filtration using *e.g.* Sepharose CL-4B, Sepharose CL-2B, Sepharose CL-6B columns and combinations thereof. Other methods of isolating virus-like particles are known in the art, and may be used to isolate the virus-like particles (VLPs) of bacteriophage AP205. For example, the use of ultracentrifugation to isolate VLPs of the yeast retrotransposon Ty is described in U.S. Patent No. 4,918,166, which is incorporated by reference herein in its entirety.

The crystal structure of several RNA bacteriophages has been determined (Golmohammadi, R. *et al., Structure 4*:543-554 (1996)). Using such information, surface exposed residues can be identified and, thus, RNA-phage coat proteins can be modified such that one or more reactive amino acid residues can be inserted by way of insertion or substitution. As a consequence, those modified forms of bacteriophage coat proteins can also be used for the present invention. Thus, variants of proteins which form capsids or capsid-like structures (*e.g.*, coat proteins of

bacteriophage Qβ, bacteriophage R17, bacteriophage fr, bacteriophage GA, bacteriophage SP, bacteriophage AP205, and bacteriophage MS2) can also be used to prepare compositions of the present invention.

Although the sequence of the variants proteins discussed above will differ from their wild-type counterparts, these variant proteins will generally retain the ability to form capsids or capsid-like structures. Thus, the invention further includes compositions and vaccine compositions, respectively, which further includes variants of proteins which form capsids or capsid-like structures, as well as methods for preparing such compositions and vaccine compositions, respectively, individual protein subunits used to prepare such compositions, and nucleic acid molecules which encode these protein subunits. Thus, included within the scope of the invention are variant forms of wild-type proteins which form capsids or capsid-like structures and retain the ability to associate and form capsids or capsid-like structures.

As a result, the invention further includes compositions and vaccine compositions, respectively, comprising proteins, which comprise, or alternatively consist essentially of, or alternatively consist of amino acid sequences which are at least 80%, 85%, 90%, 95%, 97%, or 99% identical to wild-type proteins which form ordered arrays and have an inherent repetitive structure, respectively.

Further included within the scope of the invention are nucleic acid molecules which encode proteins used to prepare compositions of the present invention.

In other embodiments, the invention further includes compositions comprising proteins, which comprise, or alternatively consist essentially of, or alternatively consist of amino acid sequences which are at least 80%, 85%, 90%, 95%, 97%, or 99% identical to any of the amino acid sequences shown in SEQ ID NOs:4-21.

Proteins suitable for use in the present invention also include C-terminal truncation mutants of proteins which form capsids or capsid-like structures, or VLPs. Specific examples of such truncation mutants include proteins having an amino acid sequence shown in any of SEQ ID NOs:4-21 where 1, 2, 5, 7, 9, 10, 12, 14, 15, or 17 amino acids have been removed from the C-terminus. Typically, theses C-terminal truncation mutants will retain the ability to form capsids or capsid-like structures.

Further proteins suitable for use in the present invention also include N-terminal truncation mutants of proteins which form capsids or capsid-like structures. Specific examples of such truncation mutants include proteins having an amino acid sequence shown in any of SEQ ID NOs:4-21 where 1, 2, 5, 7, 9, 10, 12, 14, 15, or 17 amino acids have been removed from the N-terminus. Typically, these N-terminal truncation mutants will retain the ability to form capsids or capsid-like structures.

Additional proteins suitable for use in the present invention include N- and C-terminal truncation mutants which form capsids or capsid-like structures. Suitable truncation mutants include proteins having an amino acid sequence shown in any of SEQ ID NOs:4-21 where 1, 2, 5, 7, 9, 10, 12, 14, 15, or 17 amino acids have been removed from the N-terminus and 1, 2, 5, 7, 9, 10, 12, 14, 15, or 17 amino acids have been removed from the C-terminus. Typically, these N-terminal and C-terminal truncation mutants will retain the ability to form capsids or capsid-like structures.

The invention further includes compositions comprising proteins which comprise, or alternatively consist essentially of, or alternatively consist of, amino acid sequences which are at least 80%, 85%, 90%, 95%, 97%, or 99% identical to the above described truncation mutants.

The invention thus includes compositions and vaccine compositions prepared from proteins which form capsids or VLPs, methods for preparing these compositions from individual protein subunits and VLPs or capsids, methods for preparing these individual protein subunits, nucleic acid molecules which encode these subunits, and methods for vaccinating and/or eliciting immunological responses in individuals using these compositions of the present invention.

As previously stated, the invention includes virus-like particles or recombinant forms thereof. In one further preferred embodiment, the particles used in compositions of the invention are composed of a Hepatitis B core protein (HBcAg) or a fragment of a HBcAg. In a further embodiment, the particles used in compositions of the invention are composed of a Hepatitis B core protein (HBcAg) or a fragment of a HBcAg protein, which has been modified to either eliminate or reduce the number of free cysteine residues. Zhou *et al.* (*J. Virol.* *66*:5393-5398 (1992)) demonstrated that HBcAgs which have been modified to remove the

naturally resident cysteine residues retain the ability to associate and form capsids. Thus, VLPs suitable for use in compositions of the invention include those comprising modified HBcAgs, or fragments thereof, in which one or more of the naturally resident cysteine residues have been either deleted or substituted with another amino acid residue (*e.g.*, a serine residue).

The HBcAg is a protein generated by the processing of a Hepatitis B core antigen precursor protein. A number of isotypes of the HBcAg have been identified and their amino acids sequences are readily available to those skilled in the art. In most instances, compositions and vaccine compositions, respectively, of the invention will be prepared using the processed form of a HBcAg (*i.e.*, a HBcAg from which the N-terminal leader sequence of the Hepatitis B core antigen precursor protein have been removed).

Further, when HBcAgs are produced under conditions where processing will not occur, the HBcAgs will generally be expressed in "processed" form. For example, when an *E. coli* expression system directing expression of the protein to the cytoplasm is used to produce HBcAgs of the invention, these proteins will generally be expressed such that the N-terminal leader sequence of the Hepatitis B core antigen precursor protein is not present.

The preparation of Hepatitis B virus-like particles, which can be used for the present invention, is disclosed, for example, in WO 00/32227, and hereby in particular in Examples 17 to 19 and 21 to 24, as well as in WO 01/85208, and hereby in particular in Examples 17 to 19, 21 to 24, 31 and 41, and in WO 02/056905. For the latter application, it is in particular referred to Example 23, 24, 31 and 51. All three documents are explicitly incorporated herein by reference.

The present invention also includes HBcAg variants which have been modified to delete or substitute one or more additional cysteine residues. It is known in the art that free cysteine residues can be involved in a number of chemical side reactions. These side reactions include disulfide exchanges, reaction with chemical substances or metabolites that are, for example, injected or formed in a combination therapy with other substances, or direct oxidation and reaction with nucleotides upon exposure to UV light. Toxic adducts could thus be generated, especially considering the fact that HBcAgs have a strong tendency to bind nucleic acids. The toxic adducts

would thus be distributed between a multiplicity of species, which individually may each be present at low concentration, but reach toxic levels when together.

In view of the above, one advantage to the use of HBcAgs in vaccine compositions which have been modified to remove naturally resident cysteine residues is that sites to which toxic species can bind when antigens or antigenic determinants are attached would be reduced in number or eliminated altogether.

A number of naturally occurring HBcAg variants suitable for use in the practice of the present invention have been identified. Yuan *et al.*, (*J. Virol.* *73*:10122-10128 (1999)), for example, describe variants in which the isoleucine residue at position corresponding to position 97 in SEQ ID NO:22 is replaced with either a leucine residue or a phenylalanine residue. The amino acid sequences of a number of HBcAg variants, as well as several Hepatitis B core antigen precursor variants, are disclosed in GenBank reports AAF121240, AF121239, X85297, X02496, X85305, X85303, AF151735, X85259, X85286, X85260, X85317, X85298, AF043593, M20706, X85295, X80925, X85284, X85275, X72702, X85291, X65258, X85302, M32138, X85293, X85315, U95551, X85256, X85316, X85296, AB033559, X59795, X85299, X85307, X65257, X85311, X85301 (SEQ ID NO:23), X85314, X85287, X85272, X85319, AB010289, X85285, AB010289, AF121242, M90520 (SEQ ID NO:24), P03153, AF110999, and M95589, the disclosures of each of which are incorporated herein by reference. The sequences of the hereinabove mentioned Hepatitis B core antigen precursor variants are further disclosed in WO 01/85208 in SEQ ID NOs: 89 – 138. These HBcAg variants differ in amino acid sequence at a number of positions, including amino acid residues which corresponds to the amino acid residues located at positions 12, 13, 21, 22, 24, 29, 32, 33, 35, 38, 40, 42, 44, 45, 49, 51, 57, 58, 59, 64, 66, 67, 69, 74, 77, 80, 81, 87, 92, 93, 97, 98, 100, 103, 105, 106, 109, 113, 116, 121, 126, 130, 133, 135, 141, 147, 149, 157, 176, 178, 182 and 183 in SEQ ID NO:25. Further HBcAg variants suitable for use in the compositions of the invention, and which may be further modified according to the disclosure of this specification are described in WO 00/198333, WO 00/177158 and WO 00/214478.

As noted above, generally processed HBcAgs (*i.e.*, those which lack leader sequences) will be used in the compositions and vaccine compositions, respectively,

of the invention. The present invention includes vaccine compositions, as well as methods for using these compositions, which employ the above described variant HBcAgs.

Whether the amino acid sequence of a polypeptide has an amino acid sequence that is at least 80%, 85%, 90%, 95%, 97% or 99% identical to one of the above wild-type amino acid sequences, or a subportion thereof, can be determined conventionally using known computer programs such the Bestfit program. When using Bestfit or any other sequence alignment program to determine whether a particular sequence is, for instance, 95% identical to a reference amino acid sequence, the parameters are set such that the percentage of identity is calculated over the full length of the reference amino acid sequence and that gaps in homology of up to 5% of the total number of amino acid residues in the reference sequence are allowed.

The amino acid sequences of the hereinabove mentioned HBcAg variants and precursors are relatively similar to each other. Thus, reference to an amino acid residue of a HBcAg variant located at a position which corresponds to a particular position in SEQ ID NO:25, refers to the amino acid residue which is present at that position in the amino acid sequence shown in SEQ ID NO:25. The homology between these HBcAg variants is for the most part high enough among Hepatitis B viruses that infect mammals so that one skilled in the art would have little difficulty reviewing both the amino acid sequence shown in SEQ ID NO:25 and that of a particular HBcAg variant and identifying "corresponding" amino acid residues. Furthermore, the HBcAg amino acid sequence shown in SEQ ID NO:24, which shows the amino acid sequence of a HBcAg derived from a virus which infect woodchucks, has enough homology to the HBcAg having the amino acid sequence shown in SEQ ID NO:25 that it is readily apparent that a three amino acid residue insert is present in SEQ ID NO:25 between amino acid residues 155 and 156 of SEQ ID NO:25.

The invention also includes vaccine compositions which comprise HBcAg variants of Hepatitis B viruses which infect birds, as wells as vaccine compositions which comprise fragments of these HBcAg variants. For these HBcAg variants one, two, three or more of the cysteine residues naturally present in these polypeptides

could be either substituted with another amino acid residue or deleted prior to their inclusion in vaccine compositions of the invention.

As discussed above, the elimination of free cysteine residues reduces the number of sites where toxic components can bind to the HBcAg, and also eliminates sites where cross-linking of lysine and cysteine residues of the same or of neighboring HBcAg molecules can occur. Therefore, in another embodiment of the present invention, one or more cysteine residues of the Hepatitis B virus capsid protein have been either deleted or substituted with another amino acid residue.

In other embodiments, compositions and vaccine compositions, respectively, of the invention will contain HBcAgs from which the C-terminal region (*e.g.*, amino acid residues 145-185 or 150-185 of SEQ ID NO: 25) has been removed. Thus, additional modified HBcAgs suitable for use in the practice of the present invention include C-terminal truncation mutants. Suitable truncation mutants include HBcAgs where 1, 5, 10, 15, 20, 25, 30, 34, 35, amino acids have been removed from the C-terminus.

HBcAgs suitable for use in the practice of the present invention also include N-terminal truncation mutants. Suitable truncation mutants include modified HBcAgs where 1, 2, 5, 7, 9, 10, 12, 14, 15, or 17 amino acids have been removed from the N-terminus.

Further HBcAgs suitable for use in the practice of the present invention include N- and C-terminal truncation mutants. Suitable truncation mutants include HBcAgs where 1, 2, 5, 7, 9, 10, 12, 14, 15, and 17 amino acids have been removed from the N-terminus and 1, 5, 10, 15, 20, 25, 30, 34, 35 amino acids have been removed from the C-terminus.

The invention further includes compositions and vaccine compositions, respectively, comprising HBcAg polypeptides comprising, or alternatively essentially consisting of, or alternatively consisting of, amino acid sequences which are at least 80%, 85%, 90%, 95%, 97%, or 99% identical to the above described truncation mutants.

In certain embodiments of the invention, a lysine residue is introduced into a HBcAg polypeptide, to mediate the binding of the Aβ1-6 peptide to the VLP of HBcAg. In preferred embodiments, compositions of the invention are prepared using

a HBcAg comprising, or alternatively consisting of, amino acids 1-144, or 1-149, 1-185 of SEQ ID NO:25, which is modified so that the amino acids corresponding to positions 79 and 80 are replaced with a peptide having the amino acid sequence of Gly-Gly-Lys-Gly-Gly (SEQ ID NO:33) resulting in the HBcAg polypeptide having the sequence shown in SEQ ID NO: 26. These compositions are particularly useful in those embodiments where an antigenic determinant is coupled to a VLP of HBcAg. In further preferred embodiments, the cysteine residues at positions 48 and 107 of SEQ ID NO:25 are mutated to serine. The invention further includes compositions comprising the corresponding polypeptides having amino acid sequences shown in any of the hereinabove mentioned Hepatitis B core antigen precursor variants which also have above noted amino acid alterations. Further included within the scope of the invention are additional HBcAg variants which are capable of associating to form a capsid or VLP and have the above noted amino acid alterations. Thus, the invention further includes compositions and vaccine compositions, respectively, comprising HBcAg polypeptides which comprise, or alternatively consist of, amino acid sequences which are at least 80%, 85%, 90%, 95%, 97% or 99% identical to any of the wild-type amino acid sequences, and forms of these proteins which have been processed, where appropriate, to remove the N-terminal leader sequence and modified with above noted alterations.

Compositions or vaccine compositions of the invention may comprise mixtures of different HBcAgs. Thus, these vaccine compositions may be composed of HBcAgs which differ in amino acid sequence. For example, vaccine compositions could be prepared comprising a "wild-type" HBcAg and a modified HBcAg in which one or more amino acid residues have been altered (*e.g.*, deleted, inserted or substituted). Further, preferred vaccine compositions of the invention are those which present highly ordered and repetitive antigen arrays, wherein the antigen is a Aβ1-6 peptide.

In a further preferred embodiment of the present invention, the at least one Aβ1-6 peptide is bound to said virus-like particle and core particle, respectively, by at least one covalent bond. Preferably, the least one Aβ1-6 peptide is bound to the virus-like particle and core particle, respectively, by at least one covalent bond, said covalent bond being a non-peptide bond leading to a Aβ1-6 peptide array and Aβ1-6

peptide -VLP conjugate, respectively. This Aβ1-6 peptide array and conjugate, respectively, has typically and preferably a repetitive and ordered structure since the at least one Aβ1-6 peptide is bound to the VLP and ccore particle, respectively, in an oriented manner. The formation of a repetitive and ordered Aβ1-6 peptide -VLP array and conjugate, respectively, is ensured by an oriented and directed as well as defined binding and attachment, respectively, of the at least one Aβ1-6 peptide to the VLP and core particle, respectively, as will become apparent in the following. Furthermore, the typical inherent highly repetitive and organized structure of the VLPs and core particles, respectively, advantageously contributes to the display of the Aβ1-6 peptide in a highly ordered and repetitive fashion leading to a highly organized and repetitive Aβ1-6 peptide -VLP array and conjugate, respectively.

Therefore, the preferred inventive conjugates and arrays, respectively, differ from prior art conjugates in their highly organized structure, dimensions, and in the repetitiveness of the antigen on the surface of the array. The preferred embodiment of this invention, furthermore, allows expression of the particle in an expression host guaranteeing proper folding and assembly of the VLP, to which the antigen, i.e the Aβ1-6 peptide, is then further coupled

The present invention discloses methods of binding of Aβ1-6 peptide to VLPs. As indicated, in one aspect of the invention, the Aβ1-6 peptide is bound to the VLP by way of chemical cross-linking, typically and preferably by using a heterobifunctional cross-linker. Several hetero-bifunctional cross-linkers are known to the art. In preferred embodiments, the hetero-bifunctional cross-linker contains a functional group which can react with preferred first attachment sites, i.e. with the side-chain amino group of lysine residues of the VLP or at least one VLP subunit, and a further functional group which can react with a preferred second attachment site, i.e. a cysteine residue fused to the Aβ1-6 peptide and optionally also made available for reaction by reduction. The first step of the procedure, typically called the derivatization, is the reaction of the VLP with the cross-linker. The product of this reaction is an activated VLP, also called activated carrier. In the second step, unreacted cross-linker is removed using usual methods such as gel filtration or dialysis. In the third step, the Aβ1-6 peptide is reacted with the activated VLP, and

this step is typically called the coupling step. Unreacted Aβ1-6 peptide may be optionally removed in a fourth step, for example by dialysis. Several hetero-bifunctional cross-linkers are known to the art. These include the preferred cross-linkers SMPH (Pierce), Sulfo-MBS, Sulfo-EMCS, Sulfo-GMBS, Sulfo-SIAB, Sulfo-SMPB, Sulfo-SMCC, SVSB, SIA and other cross-linkers available for example from the Pierce Chemical Company (Rockford, IL, USA), and having one functional group reactive towards amino groups and one functional group reactive towards cysteine residues. The above mentioned cross-linkers all lead to formation of a thioether linkage. Another class of cross-linkers suitable in the practice of the invention is characterized by the introduction of a disulfide linkage between the Aβ1-6 peptide and the VLP upon coupling. Preferred cross-linkers belonging to this class include for example SPDP and Sulfo-LC-SPDP (Pierce). The extent of derivatization of the VLP with cross-linker can be influenced by varying experimental conditions such as the concentration of each of the reaction partners, the excess of one reagent over the other, the pH, the temperature and the ionic strength. The degree of coupling, i.e. the amount of Aβ1-6 peptides per subunits of the VLP can be adjusted by varying the experimental conditions described above to match the requirements of the vaccine.

A particularly favored method of binding of Aβ1-6 peptides to the VLP, is the linking of a lysine residue on the surface of the VLP with a cysteine residue on the Aβ1-6 peptide. In some embodiments, fusion of an amino acid linker containing a cysteine residue, as a second attachment site or as a part thereof, to Aβ1-6 for coupling to the VLP may be required.

In general, flexible amino acid linkers are favored. Examples of the amino acid linker are selected from the group consisting of: (a) CGG; (b) N-terminal gamma 1-linker; (c) N-terminal gamma 3-linker; (d) Ig hinge regions; (e) N-terminal glycine linkers; (f) $(G)_kC(G)_n$ with n=0-12 and k=0-5 (SEQ ID NO: 34); (g) N-terminal glycine-serine linkers; (h) $(G)_kC(G)_m(S)_l(GGGGS)_n$ with n=0-3, k=0-5, m=0-10, l=0-2 (SEQ ID NO: 35); (i) GGC; (k) GGC-NH2; (l) C-terminal gamma 1-linker; (m) C-terminal gamma 3-linker; (n) C-terminal glycine linkers; (o) $(G)_nC(G)_k$ with n=0-12 and k=0-5 (SEQ ID NO: 36); (p) C-terminal glycine-serine linkers; (q)

$(G)_m(S)_l(GGGGS)_n(G)_oC(G)_k$ with n=0-3, k=0-5, m=0-10, l=0-2, and o=0-8 (SEQ ID NO: 37).

Further examples of amino acid linkers are the hinge region of Immunoglobulins, glycine serine linkers $(GGGGS)_n$ (SEQ ID NO: 38), and glycine linkers $(G)_n$ all further containing a cysteine residue as second attachment site and optionally further glycine residues. Typically preferred examples of said amino acid linkers are N-terminal gamma1: CGDKTHTSPP (SEQ ID NO: 39); C-terminal gamma 1: DKTHTSPPCG (SEQ ID NO: 40); N-terminal gamma 3: CGGPKPSTPPGSSGGAP (SEQ ID NO: 41); C-terminal gamma 3: PKPSTPPGSSGGAPGGCG (SEQ ID NO: 42); N-terminal glycine linker: GCGGGG (SEQ ID NO: 43) and C-terminal glycine linker: GGGGCG (SEQ ID NO: 44).

Other amino acid linkers particularly suitable in the practice of the invention, when a hydrophobic Aβ pepide is bound to a VLP, are CGKKGG (SEQ ID NO: 46), or CGDEGG (SEQ ID NO: 31) for N-terminal linkers, or GGKKGC (SEQ ID NO: 45) and GGEDGC (SEQ ID NO: 32), for the C-terminal linkers. For the C-terminal linkers, the terminal cysteine is optionally C-terminally amidated.

In preferred embodiments of the present invention, GGCG (SEQ ID NO: 47), GGC or GGC-NH2 ("NH2" stands for amidation) linkers at the C-terminus of the peptide or CGG at its N-terminus are preferred as amino acid linkers. In general, glycine residues will be inserted between bulky amino acids and the cysteine to be used as second attachment site, to avoid potential steric hindrance of the bulkier amino acid in the coupling reaction. In the most preferred embodiment of the invention, the amino acid linker GGC-NH2 is fused to the C-terminus of Aβ1-6.

The cysteine residue present on the Aβ1-6 peptide has to be in its reduced state to react with the hetero-bifunctional cross-linker on the activated VLP, that is a free cysteine or a cysteine residue with a free sulfhydryl group has to be available. In the instance where the cysteine residue to function as binding site is in an oxidized form, for example if it is forming a disulfide bridge, reduction of this disulfide bridge with *e.g.* DTT, TCEP or β-mercaptoethanol is required. Low concentrations of reducing agent are compatible with coupling as described in WO 02/056905, higher concentrations inhibit the coupling reaction, as a skilled artisan would know, in

which case the reductand has to be removed or its concentration decreased prior to coupling, *e.g.* by dialysis, gel filtration or reverse phase HPLC.

Binding of the Aβ1-6 peptide to the VLP by using a hetero-bifunctional cross-linker according to the preferred methods described above, allows coupling of Aβ1-6 peptide to the VLP in an oriented fashion. Other methods of binding the Aβ1-6 peptide to the VLP include methods wherein the Aβ1-6 peptide is cross-linked to the VLP using the carbodiimide EDC, and NHS. In further methods, the Aβ1-6 peptide is attached to the VLP using a homo-bifunctional cross-linker such as glutaraldehyde, DSG, $BM[PEO]_4$, BS^3, (Pierce Chemical Company, Rockford, IL, USA) or other known homo-bifunctional cross-linkers whith functional groups reactive towards amine groups or carboxyl groups of the VLP.

Other methods of binding the VLP to a Aβ1-6 peptide include methods where the VLP is biotinylated, and the Aβ1-6 peptide expressed as a streptavidin-fusion protein, or methods wherein both the Aβ1-6 peptide and the VLP are biotinylated, for example as described in WO 00/23955. In this case, the Aβ1-6 peptide may be first bound to streptavidin or avidin by adjusting the ratio of Aβ1-6 peptide to streptavidin such that free binding sites are still available for binding of the VLP, which is added in the next step. Alternatively, all components may be mixed in a "one pot" reaction. Other ligand-receptor pairs, where a soluble form of the receptor and of the ligand is available, and are capable of being cross-linked to the VLP or the Aβ1-6 peptide, may be used as binding agents for binding Aβ1-6 peptide to the VLP. Alternatively, either the ligand or the receptor may be fused to the Aβ1-6 peptide, and so mediate binding to the VLP chemically bound or fused either to the receptor, or the ligand respectively. Fusion may also be effected by insertion or substitution.

As already indicated, in a favored embodiment of the present invention, the VLP is the VLP of a RNA phage, and in a more preferred embodiment, the VLP is the VLP of RNA phage Qβ coat protein.

One or several antigen molecules, i.e. a Aβ1-6 peptide, can be attached to one subunit of the capsid or VLP of RNA phages coat proteins, preferably through the exposed lysine residues of the VLP of RNA phages, if sterically allowable. A specific feature of the VLP of the coat protein of RNA phages and in particular of the

Qβ coat protein VLP is thus the possibility to couple several antigens per subunit. This allows for the generation of a dense antigen array.

In a preferred embodiment of the invention, the binding and attachment, respectively, of the at least one Aβ1-6 peptide to the virus-like particle is by way of interaction and association, respectively, between at least one first attachment site of the virus-like particle and at least one second attachment of the antigen or antigenic determinant.

VLPs or capsids of Qβ coat protein display a defined number of lysine residues on their surface, with a defined topology with three lysine residues pointing towards the interior of the capsid and interacting with the RNA, and four other lysine residues exposed to the exterior of the capsid. These defined properties favor the attachment of antigens to the exterior of the particle, rather than to the interior of the particle where the lysine residues interact with RNA. VLPs of other RNA phage coat proteins also have a defined number of lysine residues on their surface and a defined topology of these lysine residues.

In further preferred embodiments of the present invention, the first attachment site is a lysine residue and/or the second attachment comprises sulfhydryl group or a cysteine residue. In a very preferred embodiment of the present invention, the first attachment site is a lysine residue and the second attachment is a cysteine residue.

In very preferred embodiments of the invention, the Aβ1-6 peptide is bound via a cysteine residue, to lysine residues of the VLP of RNA phage coat protein, and in particular to the VLP of Qβ coat protein.

Another advantage of the VLPs derived from RNA phages is their high expression yield in bacteria that allows production of large quantities of material at affordable cost.

As indicated, the inventive conjugates and arrays, respectively, differ from prior art conjugates in their highly organized structure, dimensions, and in the repetitiveness of the antigen on the surface of the array. Moreover, the use of the VLPs as carriers allow the formation of robust antigen arrays and conjugates, respectively, with variable antigen density. In particular, the use of VLPs of RNA phages, and hereby in particular the use of the VLP of RNA phage Qβ coat protein allows achieving very high epitope density. In particular, a density of more than 1.5

epitopes per subunit could be reached by coupling the human Aβ1-6 peptide to the VLP of Qβ coat protein. The preparation of compositions of VLPs of RNA phage coat proteins with a high epitope density can be effected using the teaching of this application. In prefered embodiment of the invention, when a Aβ1-6 peptide is coupled to the VLP of Qβ coat protein, an average number of Aβ1-6 peptide per subunit of 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6 , 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4 2.5, 2.6, 2.7, 2.8, 2.9, or higher is preferred.

The second attachment site, as defined herein, may be either naturally or non-naturally present with the antigen or the antigenic determinant. In the case of the absence of a suitable natural occurring second attachment site on the antigen or antigenic determinant, such a, then non-natural second attachment has to be engineered to the antigen.

As described above, four lysine residues are exposed on the surface of the VLP of Qβ coat protein. Typically these residues are derivatized upon reaction with a cross-linker molecule. In the instance where not all of the exposed lysine residues can be coupled to an antigen, the lysine residues which have reacted with the cross-linker are left with a cross-linker molecule attached to the ε-amino group after the derivatization step. This leads to disappearance of one or several positive charges, which may be detrimental to the solubility and stability of the VLP. By replacing some of the lysine residues with arginines, as in the disclosed Qβ coat protein mutants described below, we prevent the excessive disappearance of positive charges since the arginine residues do not react with the cross-linker. Moreover, replacement of lysine residues by arginines may lead to more defined antigen arrays, as fewer sites are available for reaction to the antigen.

Accordingly, exposed lysine residues were replaced by arginines in the following Qβ coat protein mutants and mutant Qβ VLPs disclosed in this application: Qβ-240 (Lys13-Arg; SEQ ID NO:17), Qβ-250 (Lys 2-Arg, Lys13-Arg; SEQ ID NO: 19) and Qβ-259 (Lys 2-Arg, Lys16-Arg; SEQ ID NO:21). The constructs were cloned, the proteins expressed, the VLPs purified and used for coupling to peptide and protein antigens. Qβ-251 ; (SEQ ID NO: 20 was also constructed, and guidance

on how to express, purify and couple the VLP of Qβ-251 coat protein can be found throughout the application.

In a further embodiment, we disclose a Qβ mutant coat protein with one additional lysine residue, suitable for obtaining even higher density arrays of antigens. This mutant Qβ coat protein, Qβ-243 (Asn 10-Lys; SEQ ID NO: 18), was cloned, the protein expressed, and the capsid or VLP isolated and purified, showing that introduction of the additional lysine residue is compatible with self-assembly of the subunits to a capsid or VLP. Thus, Aβ1-6 peptide arrays and conjugates, respectively, may be prepared using VLP of Qβ coat protein mutants. A particularly favored method of attachment of antigens to VLPs, and in particular to VLPs of RNA phage coat proteins is the linking of a lysine residue present on the surface of the VLP of RNA phage coat proteins with a cysteine residue added to the antigen, i.e. the Aβ1-6 peptide. In order for a cysteine residue to be effective as second attachment site, a sulfhydryl group must be available for coupling. Thus, a cysteine residue has to be in its reduced state, that is, a free cysteine or a cysteine residue with a free sulfhydryl group has to be available. In the instant where the cysteine residue to function as second attachment site is in an oxidized form, for example if it is forming a disulfide bridge, reduction of this disulfide bridge with *e.g.* DTT, TCEP or β-mercaptoethanol is required. The concentration of reductand, and the molar excess of reductand over antigen has to be adjusted for each antigen. A titration range, starting from concentrations as low as 10 μM or lower, up to 10 to 20 mM or higher reductand if required is tested, and coupling of the antigen to the carrier assessed. Although low concentrations of reductand are compatible with the coupling reaction as described in WO 02/056905, higher concentrations inhibit the coupling reaction, as a skilled artisan would know, in which case the reductand has to be removed or its concentration decreased, *e.g.* by dialysis, gel filtration or reverse phase HPLC . Advantageously, the pH of the dialysis or equilibration buffer is lower than 7, preferably 6. The compatibility of the low pH buffer with antigen activity or stability has to be tested.

Epitope density on the VLP of RNA phage coat proteins can be modulated by the choice of cross-linker and other reaction conditions. For example, the cross-linkers Sulfo-GMBS and SMPH typically allow reaching high epitope density.

Derivatization is positively influenced by high concentration of reactands, and manipulation of the reaction conditions can be used to control the number of antigens coupled to VLPs of RNA phage coat proteins, and in particular to VLPs of Qβ coat protein.

Prior to the design of a non-natural second attachment site the position at which it should be fused, inserted or generally engineered has to be chosen. The selection of the position of the second attachment site may, by way of example, be based on a crystal structure of the antigen. Such a crystal structure of the antigen may provide information on the availability of the C- or N-termini of the molecule (determined for example from their accessibility to solvent), or on the exposure to solvent of residues suitable for use as second attachment sites, such as cysteine residues. Exposed disulfide bridges, as is the case for Fab fragments, may also be a source of a second attachment site, since they can be generally converted to single cysteine residues through mild reduction, with e.g. 2-mercaptoethylamine, TCEP, β-mercaptoethanol or DTT. Mild reduction conditions not affecting the immunogenicity of the antigen will be chosen. In general, in the case where immunization with a self-antigen is aiming at inhibiting the interaction of this self-antigen with its natural ligands, the second attachment site will be added such that it allows generation of antibodies against the site of interaction with the natural ligands. Thus, the location of the second attachment site will be selected such that steric hindrance from the second attachment site or any amino acid linker containing the same is avoided. In further embodiments, an antibody response directed at a site distinct from the interaction site of the self-antigen with its natural ligand is desired. In such embodiments, the second attachment site may be selected such that it prevents generation of antibodies against the interaction site of the self-antigen with its natural ligands.

Other criteria in selecting the position of the second attachment site include the oligomerization state of the antigen, the site of oligomerization, the presence of a cofactor, and the availability of experimental evidence disclosing sites in the antigen structure and sequence where modification of the antigen is compatible with the function of the self-antigen, or with the generation of antibodies recognizing the self-antigen.

In the most preferred embodiments, the Aβ1-6 peptide comprises a single second attachment site or a single reactive attachment site capable of association with the first attachment sites on the core particle and the VLPs or VLP subunits, respectively. This ensures a defined and uniform binding and association, respectively, of the at least one, but typically more than one, preferably more than 10, 20, 40, 80, 120, 150, 180, 210, 240, 270, 300, 360, 400, 450 antigens to the core particle and VLP, respectively. The provision of a single second attachment site or a single reactive attachment site on the antigen, thus, ensures a single and uniform type of binding and association, respectively leading to a very highly ordered and repetitive array. For example, if the binding and association, respectively, is effected by way of a lysine- (as the first attachment site) and cysteine- (as a second attachment site) interaction, it is ensured, in accordance with this preferred embodiment of the invention, that only one cysteine residue per antigen, independent whether this cysteine residue is naturally or non-naturally present on the antigen, is capable of binding and associating, respectively, with the VLP and the first attachment site of the core particle, respectively.

In some embodiments, engineering of a second attachment site onto the antigen require the fusion of an amino acid linker containing an amino acid suitable as second attachment site according to the disclosures of this invention. Therefore, in a preferred embodiment of the present invention, an amino acid linker is bound to the antigen or the antigenic determinant by way of at least one covalent bond. Preferably, the amino acid linker comprises, or alternatively consists of, the second attachment site. In a further preferred embodiment, the amino acid linker comprises a sulfhydryl group or a cysteine residue. In another preferred embodiment, the amino acid linker is cysteine. Some criteria of selection of the amino acid linker as well as further preferred embodiments of the amino acid linker according to the invention have already been mentioned above.

In a further preferred embodiment of the invention, the at least one antigen or antigenic determinant, i.e. the Aβ1-6 peptide is fused to the virus-like particle. As outlined above, a VLP is typically composed of at least one subunit assembling into a VLP. Thus, in again a further preferred embodiment of the invention, the antigen or antigenic determinant, preferably the at least one Aβ1-6 peptide is fused to at least

one subunit of the virus-like particle or of a protein capable of being incorporated into a VLP generating a chimeric VLP-subunit- Aβ1-6 peptide protein fusion.

Fusion of the Aβ1-6 peptides can be effected by insertion into the VLP subunit sequence, or by fusion to either the N- or C-terminus of the VLP-subunit or protein capable of being incorporated into a VLP. Hereinafter, when referring to fusion proteins of a peptide to a VLP subunit, the fusion to either ends of the subunit sequence or internal insertion of the peptide within the subunit sequence are encompassed.

Fusion may also be effected by inserting the Aβ1-6 peptide sequences into a variant of a VLP subunit where part of the subunit sequence has been deleted, that are further referred to as truncation mutants. Truncation mutants may have N- or C-terminal, or internal deletions of part of the sequence of the VLP subunit. For example, the specific VLP HBcAg with, for example, deletion of amino acid residues 79 to 81 is a truncation mutant with an internal deletion. Fusion of Aβ1-6 peptides to either the N- or C-terminus of the truncation mutants VLP-subunits also lead to embodiments of the invention. Likewise, fusion of an epitope into the sequence of the VLP subunit may also be effected by substitution, where for example for the specific VLP HBcAg, amino acids 79-81 are replaced with a foreign epitope. Thus, fusion, as referred to hereinafter, may be effected by insertion of the Aβ1-6 peptide sequence in the sequence of a VLP subunit, by substitution of part of the sequence of the VLP subunit with the Aβ1-6 peptide, or by a combination of deletion, substitution or insertions.

The chimeric Aβ1-6 peptide-VLP subunit will be in general capable of self-assembly into a VLP. VLP displaying epitopes fused to their subunits are also herein referred to as chimeric VLPs. As indicated, the virus-like particle comprises or alternatively is composed of at least one VLP subunit. In a further embodiment of the invention, the virus-like particle comprises or alternatively is composed of a mixture of chimeric VLP subunits and non-chimeric VLP subunits, i.e. VLP subunits not having an antigen fused thereto, leading to so called mosaic particles. This may be advantageous to ensure formation of, and assembly to a VLP. In those embodiments, the proportion of chimeric VLP-subunits may be 1, 2, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95% or higher.

Flanking amino acid residues may be added to either end of the sequence of the peptide or epitope to be fused to either end of the sequence of the subunit of a VLP, or for internal insertion of such peptidic sequence into the sequence of the subunit of a VLP. Glycine and serine residues are particularly favored amino acids to be used in the flanking sequences added to the peptide to be fused. Glycine residues confer additional flexibility, which may diminish the potentially destabilizing effect of fusing a foreign sequence into the sequence of a VLP subunit.

In a specific embodiment of the invention, the VLP is a Hepatitis B core antigen VLP. Fusion proteins of the Aβ1-6 peptide to either the N-terminus of a HBcAg (Neyrinck, S. *et al., Nature Med. 5*:1157-1163 (1999)) or insertions in the so called major immunodominant region (MIR) have been described (Pumpens, P. and Grens, E., *Intervirology 44*:98-114 (2001)), WO 01/98333), and are preferred embodiments of the invention. Naturally occurring variants of HBcAg with deletions in the MIR have also been described (Pumpens, P. and Grens, E., *Intervirology 44*:98-114 (2001), which is expressly incorporated by reference in its entirety), and fusions to the N- or C-terminus, as well as insertions at the position of the MIR corresponding to the site of deletion as compared to a wt HBcAg are further embodiments of the invention. Fusions to the C-terminus have also been described (Pumpens, P. and Grens, E., *Intervirology 44*:98-114 (2001)). One skilled in the art will easily find guidance on how to construct fusion proteins using classical molecular biology techniques (Sambrook, J.*et al.*, eds., *Molecular Cloning, A Laboratory Manual*, 2nd. edition, Cold Spring Habor Laboratory Press, Cold Spring Harbor, N.Y. (1989), Ho *et al.*, *Gene 77*:51 (1989)). Vectors and plasmids encoding HBcAg and HBcAg fusion proteins and useful for the expression of a HBcAg and HBcAg fusion proteins have been described (Pumpens, P. & Grens, E. Intervirology 44: 98-114 (2001), Neyrinck, S. *et al., Nature Med. 5*:1157-1163 (1999)) and can be used in the practice of the invention. We also describe by way of example (Example 6) the insertion of an epitope into the MIR of HBcAg, resulting in a chimeric self-assembling HBcAg. An important factor for the optimization of the efficiency of self-assembly and of the display of the epitope to be inserted in the MIR of HBcAg is the choice of the insertion site, as well as the number of amino acids to be deleted from the HBcAg sequence within the MIR (Pumpens, P. and Grens, E., *Intervirology*

44:98-114 (2001); EP 0 421 635; U.S. Patent No. 6,231,864) upon insertion, or in other words, which amino acids form HBcAg are to be substituted with the new epitope. For example, substitution of HBcAg amino acids 76-80, 79-81, 79-80, 75-85 or 80-81 with foreign epitopes has been described (Pumpens, P. and Grens, E., *Intervirology 44*:98-114 (2001); EP0421635; US 6'231'864). HBcAg contains a long arginine tail (Pumpens, P. and Grens, E., *Intervirology 44*:98-114 (2001))which is dispensable for capsid assembly and capable of binding nucleic acids (Pumpens, P. and Grens, E., *Intervirology 44*:98-114 (2001)). HBcAg either comprising or lacking this arginine tail are both embodiments of the invention.

In a further preferred embodiment of the invention, the VLP is a VLP of a RNA phage. The major coat proteins of RNA phages spontaneously assemble into VLPs upon expression in bacteria, and in particular in *E. coli*. Specific examples of bacteriophage coat proteins which can be used to prepare compositions of the invention include the coat proteins of RNA bacteriophages such as bacteriophage Qβ (SEQ ID NO:4; PIR Database, Accession No. VCBPQβ referring to Qβ CP and SEQ ID NO: 5; Accession No. AAA16663 referring to Qβ A1 protein) and bacteriophage fr (SEQ ID NO: 7; PIR Accession No. VCBPFR).

In a more preferred embodiment, the at least one Aβ1-6 peptide is fused to a Qβ coat protein. Fusion protein constructs wherein epitopes have been fused to the C-terminus of a truncated form of the A1 protein of Qβ, or inserted within the A1 protein have been described (Kozlovska, T. M., *et al., Intervirology, 39*:9-15 (1996)). The A1 protein is generated by suppression at the UGA stop codon and has a length of 329 aa, or 328 aa, if the cleavage of the N-terminal methionine is taken into account. Cleavage of the N-terminal methionine before an alanine (the second amino acid encoded by the Qβ CP gene) usually takes place in *E. coli*, and such is the case for N-termini of the Qβ coat proteins. The part of the A1 gene, 3' of the UGA amber codon encodes the CP extension, which has a length of 195 amino acids. Insertion of the at least one Aβ1-6 peptide between position 72 and 73 of the CP extension leads to further embodiments of the invention (Kozlovska, T. M., *et al., Intervirology 39*:9-15 (1996)). Fusion of a Aβ1-6 peptide at the C-terminus of a C-terminally truncated Qβ A1 protein leads to further preferred embodiments of the invention. For example,

Kozlovska et al., (*Intervirology, 39*: 9-15 (1996)) describe Qβ A1 protein fusions where the epitope is fused at the C-terminus of the Qβ CP extension truncated at position 19.

As described by Kozlovska et al. (*Intervirology, 39*: 9-15 (1996)), assembly of the particles displaying the fused epitopes typically requires the presence of both the A1 protein-Aβ1-6 peptide fusion and the wt CP to form a mosaic particle. However, embodiments comprising virus-like particles, and hereby in particular the VLPs of the RNA phage Qβ coat protein, which are exclusively composed of VLP subunits having at least one Aβ1-6 peptide fused thereto, are also within the scope of the present invention.

The production of mosaic particles may be effected in a number of ways. Kozlovska *et al., Intervirology, 39*:9-15 (1996), describe three methods, which all can be used in the practice of the invention. In the first approach, efficient display of the fused epitope on the VLPs is mediated by the expression of the plasmid encoding the Qβ A1 protein fusion having a UGA stop codong between CP and CP extension in a E. coli strain harboring a plasmid encoding a cloned UGA suppressor tRNA which leads to translation of the UGA codon into Trp (pISM3001 plasmid (Smiley B.K., *et al., Gene 134*:33-40 (1993))). In another approach, the CP gene stop codon is modified into UAA, and a second plasmid expressing the A1 protein-Aβ1-6 peptide fusion is cotransformed. The second plasmid encodes a different antibiotic resistance and the origin of replication is compatible with the first plasmid (Kozlovska, T. M., *et al., Intervirology 39*:9-15 (1996)). In a third approach, CP and the A1 protein-Aβ1-6 peptide fusion are encoded in a bicistronic manner, operatively linked to a promoter such as the Trp promoter, as described in FIG. 1 of Kozlovska *et al., Intervirology, 39*:9-15 (1996).

In a further embodiment, the Aβ1-6 peptide is inserted between amino acid 2 and 3 (numbering of the cleaved CP, that is wherein the N-terminal methionine is cleaved) of the fr CP, thus leading to a Aβ1-6 peptide-fr CP fusion protein. Vectors and expression systems for construction and expression of fr CP fusion proteins self-assembling to VLP and useful in the practice of the invention have been described (Pushko P. *et al., Prot. Eng. 6*:883-891 (1993)). In a specific embodiment, the Aβ1-6 peptide sequence is inserted into a deletion variant of the fr CP after amino acid 2,

wherein residues 3 and 4 of the fr CP have been deleted (Pushko P. *et al., Prot. Eng. 6*:883-891 (1993)).

Fusion of epitopes in the N-terminal protuberant β-hairpin of the coat protein of RNA phage MS-2 and subsequent presentation of the fused epitope on the self-assembled VLP of RNA phage MS-2 has also been described (WO 92/13081), and fusion of Aβ1-6 peptide by insertion or substitution into the coat protein of MS-2 RNA phage is also falling under the scope of the invention.

In another embodiment of the invention, the Aβ1-6 peptide is fused to a capsid protein of papillomavirus. In a more specific embodiment, the Aβ1-6 peptide is fused to the major capsid protein L1 of bovine papillomavirus type 1 (BPV-1). Vectors and expression systems for construction and expression of BPV-1 fusion proteins in a baculovirus/insect cells systems have been described (Chackerian, B. *et al., Proc. Natl. Acad. Sci.USA 96*:2373-2378 (1999), WO 00/23955). Substitution of amino acids 130-136 of BPV-1 L1 with a Aβ1-6 peptide leads to a BPV-1 L1-Aβ1-6 peptide fusion protein, which is a preferred embodiment of the invention. Cloning in a baculovirus vector and expression in baculovirus infected Sf9 cells has been described, and can be used in the practice of the invention (Chackerian, B. *et al., Proc. Natl. Acad. Sci.USA 96*:2373-2378 (1999), WO 00/23955). Purification of the assembled particles displaying the fused Aβ1-6 peptide can be performed in a number of ways, such as for example gel filtration or sucrose gradient ultracentrifugation (Chackerian, B. *et al., Proc. Natl. Acad. Sci.USA 96*:2373-2378 (1999), WO 00/23955).

In a further embodiment of the invention, the Aβ1-6 peptide is fused to a Ty protein capable of being incorporated into a Ty VLP. In a more specific embodiment, the Aβ1-6 peptide is fused to the p1 or capsid protein encoded by the TYA gene (Roth, J.F., *Yeast 16*:785-795 (2000)). The yeast retrotransposons Ty1, 2, 3 and 4 have been isolated from *Saccharomyces Serevisiae*, while the retrotransposon Tf1 has been isolated from Schizosaccharomyces Pombae (Boeke, J.D. and Sandmeyer, S.B., "Yeast Transposable elements," in *The molecular and Cellular Biology of the Yeast Saccharomyces: Genome dynamics, Protein Synthesis, and Energetics*, p. 193, Cold Spring Harbor Laboratory Press (1991)). The retrotransposons Ty1 and 2 are related to the *copia* class of plant and animal elements, while Ty3 belongs to the

gypsy family of retrotransposons, which is related to plants and animal retroviruses. In the Ty1 retrotransposon, the p1 protein, also referred to as Gag or capsid protein, has a length of 440 amino acids. P1 is cleaved during maturation of the VLP at position 408, leading to the p2 protein, the essential component of the VLP.

Fusion proteins to p1 and vectors for the expression of said fusion proteins in Yeast have been described (Adams, S.E., *et al., Nature 329*:68-70 (1987)). So, for example, a Aβ1-6 peptide may be fused to p1 by inserting a sequence coding for the Aβ1-6 peptide into the BamH1 site of the pMA5620 plasmid (Adams, S.E., *et al., Nature 329*:68-70 (1987)). The cloning of sequences coding for foreign epitopes into the pMA5620 vector leads to expression of fusion proteins comprising amino acids 1-381 of p1 of Ty1-15, fused C-terminally to the N-terminus of the foreign epitope. Likewise, N-terminal fusion of a Aβ1-6 peptide, or internal insertion into the p1 sequence, or substitution of part of the p1 sequence are also meant to fall within the scope of the invention. In particular, insertion of a Aβ1-6 peptide into the Ty sequence between amino acids 30-31, 67-68, 113-114 and 132-133 of the Ty protein p1 (EP0677111) leads to preferred embodiments of the invention.

Further VLPs suitable for fusion of Aβ1-6 peptides are, for example, Retrovirus-like-particles (WO9630523), HIV2 Gag (Kang, Y.C., *et al, Biol. Chem. 380*:353-364 (1999)), Cowpea Mosaic Virus (Taylor, K.M.*et al., Biol. Chem. 380*:387-392 (1999)), parvovirus VP2 VLP (Rueda, P. *et al., Virology 263*:89-99 (1999)), HBsAg (US 4,722,840, EP0020416B1).

Examples of chimeric VLPs suitable for the practice of the invention are also those described in *Intervirology 39*:1 (1996). Further examples of VLPs contemplated for use in the invention are: HPV-1, HPV-6, HPV-11, HPV-16, HPV-18, HPV-33, HPV-45, CRPV, COPV, HIV GAG, Tobacco Mosaic Virus. Virus-like particles of SV-40, Polyomavirus, Adenovirus, Herpes Simplex Virus, Rotavirus and Norwalk virus have also been made, and chimeric VLPs of those VLPs comprising a Aβ1-6 peptide are also within the scope of the present invention.

In preferred embodiments of the invention, Aβ1-6 peptides suitable for generating vaccines of the invention are modified with an amino acid linker for binding to a VLP. Those Aβ1-6 peptides include, but are not limited to: Aβ1-6 fused C-terminally to the linker GGC. Amino acid linkers suitable for fusion to the N-

terminus of Aβ1-6 fragments include but are not limited to the sequence CGG and CGHGNKS. Linkers suitable for fusion to the C-terminus of Aβ1-6 include but are not limited to the sequence GGC. In a preferred embodiment, when a linker is fused to the C-terminus of Aβ or Aβ fragments, the C-terminal Cysteine is amidated. In a preferred embodiment, Aβ1-6 is fused to an amino acid linker and has the sequence: "NH2-DAEFRHGGC-CONH2, wherein the C-terminal Cysteine is amidated, which is indicated by the C-terminal "-CONH2", and the N-terminus of the peptide is free, which is further indicated by "NH2-". Amino acid linkers are preferably short, to avoid induction of immune responses against amino acids of said linker, but should allow the induction of antibodies cross-reactive with soluble Aβ and AD plaques and may facilitate the interaction of antibodies with the Aβ1-6 peptide. Other suitable properties of the amino acid linker are flexibility, and preferably lack of bulky amino acids which might interfere with coupling, and/or generate an immune response against the linker itself. In more preferred embodiments, the amino acid linker containing a cysteine residue as second attachment site is fused to the C-terminus of the Aβ1-6 peptide.

Additional Aβ fragments suitable in the practice of the invention include Aβ fragments corresponding to the aforementioned fragments, also modified as described above, from other animal species and eliciting Antibodies cross-reactive with human amyloid plaques and soluble human Aβ. Examples of such fragments are Aβ1-6 from primates (DAEFRH; SEQ ID NO: 84), rabbit (DAEFRH; SEQ ID NO: 85), guinea pig (DAEFRH: SEQ ID NO: 88), mouse (DAEFGH; SEQ ID NO: 76), rat (DAEFGH SEQ ID NO: 87), and xaenopus laevis (DSEYRH; 86).

A number of animal models of AD based on transgenic mice overexpressing mutated forms of human APP have been reported (Games, D. *et al., Nature 373*: 523-527 (1995a); Sturchler-Pierrat *et al., Proc. Natl. Acad. Sci. USA 94*: 13287-13292 (1997); Hsiao, K., *et al., Science 274:* 99-102 (1996); Chen, G. *et al., Nature 408* : 975- 979 (2000) ; Janus, C. *et al., Nature 408* : 979-982 (2000) ; Morgan, D. *et al., Nature 408* : 982-985 (2000)). Those mice models differ from each other in the level of overexpression of the transgene, the AD mutations present on the transgene and the promoter under which overexpression of the transgene is directed. These animal models fail to display all of the pathological signs of AD, which are in

particular age-related changes in behaviour, deposition of β-amyloid into insoluble plaques, neurofibrillary tangles within neurons, and loss of neurons throughout the forebrain (Chapman, P.F. *Nature 408*: 915-916 (2000)). Memory deficits and methods to identify them could however be identified in those models, and may be used in testing the effect of the compositions of the invention in animal models (Chen, G. *et al., Nature 408* : 975- 979 (2000) ; Janus, C. *et al., Nature 408* : 979-982 (2000) ; Morgan, D. *et al., Nature 408* : 982-985 (2000)). Furthermore, age related deposition of Aβ into amyloid plaques can be studied in those models, which also develop astrocytosis and microgliosis.

It will be understood by one of ordinary skill in the relevant arts that other suitable modifications and adaptations to the methods and applications described herein are readily apparent and may be made without departing from the scope of the invention or any embodiment thereof. Having now described the present invention in detail, the same will be more clearly understood by reference to the following examples, which are included herewith for purposes of illustration only and are not intended to be limiting of the invention.

EXAMPLES

EXAMPLE 1

Cloning and construction, respectively, expression and purification of preferred core particles and VLP of RNA phages, respectively

A. Construction and expression of mutant Qβ coat proteins, and purification of mutant Qβ coat protein VLPs or Capsids.

Plasmid construction and cloning of mutant coat proteins

Construction of pQβ-240:

The plasmid pQβ10 (Kozlovska, TM, *et al., Gene 137*:133-137) was used as an initial plasmid for the construction of pQβ-240. The mutation Lys13→Arg was created by inverse PCR. The inverse primers were designed in inverted tail-to-tail directions:

5'-GGTAACATCGGTCGAGATGGAAAACAAACTCTGGTCC-3'

(SEQ ID NO: 48)

and

5'-GGACCAGAGTTTGTTTTCCATCTCGACCGATGTTACC-3'

(SEQ ID NO: 49).

The products of the first PCR were used as templates for the second PCR reaction, in which an upstream primer

5'-AGCTCGCCCGGGGATCCTCTAG-3' (SEQ ID NO: 50)

and a downstream primer

5'-CGATGCATTTCATCCTTAGTTATCAATACGCTGGGTTCAG-3' (SEQ ID NO: 51)

were used. The product of the second PCR was digested with *XbaI* and *Mph1103I* and cloned into the pQβ10 expression vector, which was cleaved by the same restriction enzymes. The PCR reactions were performed with PCR kit reagents and according to producer protocol (MBI Fermentas, Vilnius, Lithuania).

Sequencing using the direct label incorporation method verified the desired mutations. *E.coli* cells harbouring pQβ-240 supported efficient synthesis of 14-kD protein co migrating upon SDS-PAGE with control Qβ coat protein isolated from Qβ phage particles.

Resulting amino acid sequence: (SEQ ID NO: 17)

AKLETVTLGNIGRDGKQTLVLNPRGVNPTNGVASLSQAGAVP
ALEKRVTVSVSQPSRNRKNYKVQVKIQNPTACTANGSCDPSVTRQ
KYADVTFSFTQYSTDEERAFVRTELAALLASPLLIDAIDQLNPAY

Construction of pQβ-243:

The plasmid pQβ10 was used as an initial plasmid for the construction of pQβ-243.The mutation Asn10→Lys was created by inverse PCR. The inverse primers were designed in inverted tail-to-tail directions:

5'-GGCAAAATTAGAGACTGTTACTTTAGGTAAGATCGG -3'

(SEQ ID NO: 52)

and

5'-CCGATCTTACCTAAAGTAACAGTCTCTAATTTTGCC -3'

(SEQ ID NO: 53).

The products of the first PCR were used as templates for the second PCR reaction, in which an upstream primer

5'-AGCTCGCCCGGGGATCCTCTAG-3' (SEQ ID NO: 50)

and a downstream primer

5'-CGATGCATTTCATCCTTAGTTATCAATACGCTGGGTTCAG-3' (SEQ ID NO: 51)

were used. The product of the second PCR was digested with *XbaI* and *Mph1103I* and cloned into the pQβ10 expression vector, which was cleaved by the same restriction enzymes. The PCR reactions were performed with PCR kit reagents and according to producer protocol (MBI Fermentas, Vilnius, Lithuania).

Sequencing using the direct label incorporation method verified the desired mutations. *E.coli* cells harbouring pQβ-243 supported efficient synthesis of 14-kD protein co migrating upon SDSD-PAGE with control Qβ coat protein isolated from Qβ phage particles.

Resulting amino acid sequence: (SEQ ID NO: 18)

AKLETVTLGKIGKDGKQTLVLNPRGVNPTNGVASLSQAGAVP
ALEKRVTVSVSQPSRNRKNYKVQVKIQNPTACTANGSCDPSVTRQ
KYADVTFSFTQYSTDEERAFVRTELAALLASPLLIDAIDQLNPAY

Construction of pQβ-250:

The plasmid pQβ-240 was used as an initial plasmid for the construction of pQβ-250. The mutation Lys2→Arg was created by site-directed mutagenesis. An upstream primer

5'-GGCCATGGCACGACTCGAGACTGTTACTTTAGG-3' (SEQ ID NO: 54)

and a downstream primer

5'-GATTTAGGTGACACTATAG-3' (SEQ ID NO: 55)

were used for the synthesis of the mutant PCR-fragment, which was introduced into the pQβ-185 expression vector at the unique restriction sites ***NcoI*** and ***HindIII.***

The PCR reactions were performed with PCR kit reagents and according to producer protocol (MBI Fermentas, Vilnius, Lithuania).

Sequencing using the direct label incorporation method verified the desired mutations. *E.coli* cells harbouring pQβ-250 supported efficient synthesis of 14-kD protein co migrating upon PAGE with control Qβ coat protein isolated from Qβ phage particles.

Resulting amino acid sequence: (SEQ ID NO: 19)

ARLETVTLGNIGRDGKQTLVLNPRGVNPTNGVASLSQAGAVP

ALEKRVTVSVSQPSRNRKNYKVQVKIQNPTACTANGSCDPSVTRQ

KYADVTFSFTQYSTDEERAFVRTELAALLASPLLIDAIDQLNPAY

Construction of pQβ-251:

The plasmid pQβ10 was used as an initial plasmid for the construction of pQβ-251. The mutation Lys16→Arg was created by inverse PCR. The inverse primers were designed in inverted tail-to-tail directions:

5′-GATGGA**CGT**CAAACTCTGGTCCTCAATCCGCGTGGGG -3′ (SEQ ID NO: 56)

and

5′-CCCCACGCGGATTGAGGACCAGAGTTTG**ACG**TCCATC -3′ (SEQ ID NO: 57).

The products of the first PCR were used as templates for the second PCR reaction, in which an upstream primer

5′-AGCTCGCCCGGGGATCCTCTAG-3′ (SEQ ID NO: 50)

and a downstream primer

5′-CGATGCATTTCATCCTTAGTTATCAATACGCTGGGTTCAG-3′ (SEQ ID NO: 51)

were used. The product of the second PCR was digested with *XbaI* and *Mph1103I* and cloned into the pQβ10 expression vector, which was cleaved by the same restriction enzymes. The PCR reactions were performed with PCR kit reagents and according to producer protocol (MBI Fermentas, Vilnius, Lithuania).

Sequencing using the direct label incorporation method verified the desired mutations. *E.coli* cells harbouring pQβ-251 supported efficient synthesis of 14-kD

protein co migrating upon SDS-PAGE with control Qβ coat protein isolated from Qβ phage particles. The resulting amino acid sequence encoded by this construct is shown in (SEQ. ID NO: 20).

Construction of pQβ-259:

The plasmid pQβ-251 was used as an initial plasmid for the construction of pQβ-259. The mutation Lys2→Arg was created by site-directed mutagenesis. An upstream primer

5'-GGCCATGGCACGACTCGAGACTGTTACTTTAGG-3' (SEQ ID NO: 54)

and a downstream primer

5'-GATTTAGGTGACACTATAG-3' (SEQ ID NO: 55)

were used for the synthesis of the mutant PCR-fragment, which was introduced into the pQβ-185 expression vector at the unique restriction sites *NcoI* and *HindIII*. The PCR reactions were performed with PCR kit reagents and according to producer protocol (MBI Fermentas, Vilnius, Lithuania).

Sequencing using the direct label incorporation method verified the desired mutations. *E.coli* cells harbouring pQβ-259 supported efficient synthesis of 14-kD protein co migrating upon SDS-PAGE with control Qβ coat protein isolated from Qβ phage particles.

Resulting amino acid sequence: (SEQ ID NO: 21)

AKLETVTLGNIGKDGKQTLVLNPRGVNPTNGVASLSQAGAVP
ALEKRVTVSVSQPSRNRKNYKVQVKIQNPTACTANGSCDPSVTRQ
KYADVTFSFTQYSTDEERAFVRTELAALLASPLLIDAIDQLNPAY

General procedures for Expression and purification of Qβ and Qβ mutants

Expression

E.coli JM109 was transformed with Qβ coat protein expression plasmids. 5 ml of LB liquid medium containing 20 μg/ml ampicillin were inoculated with clones transformed with with Qβ coat protein expression plasmids. The inoculated culture was incubated at 37 °C for 16-24 h without shaking. The prepared inoculum was

subsequently diluted 1:100 in 100-300 ml of fresh LB medium, containing 20 µg/ml ampicillin. and incubated at 37°C overnight without shaking. The resulting second inoculum was diluted 1:50 in M9 medium containing 1 % Casamino acids and 0.2 % glucose in flasks, and incubated at 37 °C overnight under shaking.

Purification

Solutions and buffers for the purification procedure:

1. Lysis buffer LB

50mM Tris-HCl pH8,0 with 5mM EDTA , 0,1%

tritonX100 and freshly prepared PMSF at a concentration of 5micrograms per ml.Without lysozyme and DNAse.

2. SAS

Saturated ammonium sulphate in water

3. Buffer NET.

20 mM Tris-HCl, pH 7.8 with 5mM EDTA and

150 mM NaCl.

4. PEG

40% (w/v) polyethylenglycol 6000 in NET

Disruption and lysis

Frozen cells were resuspended in LB at 2 ml/g cells. The mixture was sonicated with 22 kH five times for15 seconds, with intervals of 1min to cool the solution on ice. The lysate was then centrifuged at 14 000 rpm, for 1h using a Janecki K 60 rotor. The centrifugation steps described below were all performed using the same rotor, except otherwise stated. The supernatant was stored at 4° C, while cell debris were washed twice with LB. After centrifugation, the supernatants of the lysate and wash fractions were pooled.

Fractionation

A saturated ammonium sulphate solution was added dropwise under stirring to the above pooled lysate. The volume of the SAS was adjusted to be one fifth of total volume, to obtain 20% of saturation. The solution was left standing overnight, and was centrifuged the next day at 14 000 rpm, for 20 min. The pellet was washed with

a small amount of 20% ammonium sulphate, and centrifuged again . The obtained supernatants were pooled, and SAS was added dropwise to obtain 40% of saturation. The solution was left standing overnight, and was centrifuged the next day at 14 000 rpm, for 20 min. The obtained pellet was solubilised in NET buffer.

Chromatography

The capsid or VLP protein resolubilized in NET buffer was loaded on a Sepharose CL– 4B column. Three peaks eluted during chromatography. The first one mainly contained membranes and membrane fragments, and was not collected. Capsids were contained in the second peak, while the third one contained other E.coli proteins.

The peak fractions were pooled, and the NaCl concentration was adjusted to a final concentration of 0.65 M. A volume of PEG solution corresponding to one half of the pooled peak fraction was added dropwise under stirring. The solution was left to stand overnight without stirring. The capsid protein was sedimented by centrifugation at 14 000 rpm for 20 min. It was then solubilized in a minimal volume of NET and loaded again on the Sepharose CL- 4B column. The peak fractions were pooled, and precipitated with ammonium sulphate at 60% of saturation (w/v). After centrifugation and resolubilization in NET buffer, capsid protein was loaded on a Sepharose CL-6B column for rechromatography.

Dialysis and drying

The peak fractions obtained above were pooled and extensively dialysed against sterile water, and lyophilized for storage.

Expression and purification Qβ-240

Cells (*E. coli* JM 109, transformed with the plasmid pQβ-240) were resuspended in LB, sonicated five times for 15 seconds (water ice jacket) and centrifuged at 13000 rpm for one hour. The supernatant was stored at 4°C until further processing, while the debris were washed 2 times with 9 ml of LB, and finally with 9 ml of 0,7 M urea in LB. All supernatants were pooled, and loaded on the Sepharose CL-4B column. The pooled peak fractions were precipitated with

ammonium sulphate and centrifuged. The resolubilized protein was then purified further on a Sepharose 2B column and finally on a Sepharose 6B column. The capsid peak was finally extensively dialyzed against water and lyophilized as described above. The assembly of the coat protein into a capsid was confirmed by electron microscopy.

Expression and purification Qβ-243

Cells (*E. coli* RR1) were resuspended in LB and processed as described in the general procedure. The protein was purified by two successive gel filtration steps on the sepharose CL-4B column and finally on a sepharose CL-2B column. Peak fractions were pooled and lyophilized as described above. The assembly of the coat protein into a capsid was confirmed by electron microscopy.

Expression and purification of Qβ-250

Cells (*E. coli* JM 109, transformed with pQβ-250) were resuspended in LB and processed as described above. The protein was purified by gel filtration on a Sepharose CL-4B and finally on a Sepharose CL-2B column, and lyophilized as described above. The assembly of the coat protein into a capsid was confirmed by electron microscopy.

Expression and purification of Qβ-259

Cells (*E. coli* JM 109, transformed with pQβ-259) were resuspended in LB and sonicated. The debris were washed once with 10 ml of LB and a second time with 10 ml of 0,7 M urea in LB. The protein was purified by two gel-filtration chromatogaphy steps, on a Sepharose CL-4 B column. The protein was dialyzed and lyophilized, as described above. The assembly of the coat protein into a capsid was confirmed by electron microscopy.

B. Cloning, Expression and Purification of Recombinant AP205 VLP

Cloning of the AP205 Coat Protein gene

The cDNA of AP205 coat protein (CP) (SEQ ID NO: 28) was assembled from two cDNA fragments generated from phage AP205 RNA by using a reverse transcription-PCR technique and cloning in the commercial plasmid pCR 4-TOPO for sequencing. Reverse transcription techniques are well known to those of ordinary skill in the relevant art. The first fragment, contained in plasmid p205-246, contained 269 nucleotides upstream of the CP sequence and 74 nucleotides coding for the first 24 N-terminal amino acids of the CP. The second fragment, contained in plasmid p205-262, contained 364 nucleotides coding for amino acids12-131of CP and an additional 162 nucleotides downstream of the CP sequence. Both p205-246 and p205-262 were a generous gift from J. Klovins.

The plasmid 283.-58 was designed by two-step PCR, in order to fuse both CP fragments from plasmids p205-246 and p205-262 in one full-length CP sequence.

An upstream primer p1.44 containing the *NcoI* site for cloning into plasmid pQb185, or p1.45 containing the *XbaI* site for cloning into plasmid pQb10, and a downstream primer p1.46 containing the *HindIII* restriction site were used (recognition sequence of the restriction enzyme underlined):

p1.44 5'-AACC ATG GCA AAT AAG CCA ATG CAA CCG-3' (SEQ ID NO: 79)

p1.45 5'-AATCTAGAATTTTCTGCGCACCCATCCCGG-3' (SEQ ID NO: 80)

p1.46 5'-AAAAGC TTA AGC AGT AGT ATC AGA CGA TAC G-3' (SEQ ID NO: 81)

Two additional primers, p1.47, annealing at the 5' end of the fragment contained in p205-262, and p1.48, annealing at the 3' end of the fragment contained in plasmid p205-246 were used to amplify the fragments in the first PCR. Primers p1.47 and p1.48 are complementary to each other.

p1.47: 5'-GAGTGATCCAACTCGTTTATCAACTACATTT-TCAGCAAGTCTG-3' (SEQ ID NO: 82)

p1.48: 5'-CAGACTTGCTGAAAATGTAGTTGATAAACGA-GTTGGATCACTC-3' (SEQ ID NO: 83)

In the first two PCR reactions, two fragments were generated. The first fragment was generated with primers p1.45 and p1.48 and template p205-246. The

second fragment was generated with primers p1.47 and p1.46, and template p205-262. Both fragments were used as templates for the second PCR reaction, a splice-overlap extension, with the primer combination p1.45 and p1.46 or p1.44 and p1.46 . The product of the two second-step PCR reactions were digested with *XbaI* or *NcoI* respectively, and *HindIII,* and cloned with the same restriction sites into pQb10 or pQb185 respectively, two pGEM-derived expression vectors under the control of *E.coli* tryptophan operon promoter.

Two plasmids were obtained, pAP283-58 (SEQ ID NO: 27), containing the gene coding for wt AP205 CP (SEQ ID NO: 28) in pQb10, and pAP281-32 (SEQ ID NO: 30) with mutation Pro5→Thr (SEQ ID NO: 29), in pQb185 . The coat protein sequences were verified by DNA sequencing. PAP283-58 contains 49 nucleotides upstream of the ATG codon of the CP, downstream of the XbaI site, and contains the putative original ribosomal binding site of the coat protein mRNA.

Expression and Purification of Recombinant AP205 VLP

A. Expression of recombinant AP205 VLP

E.coli JM109 was transformed with plasmid pAP283-58. 5 ml of LB liquid medium with 20 µg/ml ampicillin were inoculated with a single colony, and incubated at 37 °C for 16-24 h without shaking.

The prepared inoculum was diluted 1:100 in 100-300 ml of LB medium, containing 20 µg/ml ampicillin and incubated at 37 °C overnight without shaking. The resulting second inoculum was diluted 1:50 in 2TY medium, containing 0.2 % glucose and phosphate for buffering, and incubated at 37 °C overnight on a shaker. Cells were harvested by centrifugation and frozen at -80°C.

B. Purification of recombinant AP205 VLP

Solutions and buffers:

Lysis buffer

50mM Tris-HCl pH 8.0 with 5mM EDTA , 0.1%

tritonX100 and PMSF at 5 micrograms per ml.

SAS

Saturated ammonium sulphate in water

Buffer NET.

20 mM Tris-HCl, pH 7.8 with 5mM EDTA and 150 mM NaCl.

PEG

40% (w/v) polyethylenglycol 6000 in NET

Lysis:

Frozen cells were resuspended in lysis buffer at 2 ml/g cells. The mixture was sonicated with 22 kH five times for15 seconds, with intervals of 1min to cool the solution on ice. The lysate was then centrifuged for 20 minutes at 12 000 rpm, using a F34-6-38 rotor (Ependorf). The centrifugation steps described below were all performed using the same rotor, except otherwise stated. The supernatant was stored at 4° C, while cell debris were washed twice with lysis buffer. After centrifugation, the supernatants of the lysate and wash fractions were pooled.

Ammonium-sulphate precipitation can be further used to purify AP205 VLP. In a first step, a concentration of ammonium-sulphate at which AP205 VLP does not precipitate is chosen. The resulting pellet is discarded. In the next step, an ammonium sulphate concentration at which AP205 VLP quantitatively precipitates is selected, and AP205 VLP is isolated from the pellet of this precipitation step by centrifugation (14 000 rpm, for 20 min). The obtained pellet is solubilised in NET buffer.

Chromatography:

The capsid protein from the pooled supernatants was loaded on a Sepharose 4B column (2.8 X 70 cm), and eluted with NET buffer, at 4 ml/hour/fraction. Fractions 28-40 were collected, and precipitated with ammonium sulphate at 60% saturation. The fractions were analyzed by SDS-PAGE and Western Blot with an antiserum specific for AP205 prior to precipitation. The pellet isolated by

centrifugation was resolubilized in NET buffer, and loaded on a Sepharose 2B column (2.3 X 65 cm), eluted at 3 ml/h/fraction. Fractions were analysed by SDS-PAGE, and fractions 44-50 were collected, pooled and precipitated with ammonium sulphate at 60% saturation. The pellet isolated by centrifugation was resolubilized in NET buffer, and purified on a Sepharose 6B column (2.5 X 47 cm), eluted at 3 ml/hour/fraction. The fractions were analysed by SDS-PAGE. Fractions 23-27 were collected, the salt concentration adjusted to 0.5 M, and precipitated with PEG 6000, added from a 40% stock in water and to a final concentration of 13.3%. The pellet isolated by centrifugation was resolubilized in NET buffer, and loaded on the same Sepharose 2B column as above, eluted in the same manner. Fractions 43-53 were collected, and precipitated with ammonium sulphate at a saturation of 60%. The pellet isolated by centrifugation was resolubilized in water, and the obtained protein solution was extensively dialyzed against water. About 10 mg of purified protein per gram of cells could be isolated.

Examination of the virus-like particles in Electron microscopy showed that they were identical to the phage particles.

EXAMPLE 2

Insertion of a peptide containing a Lysine residue into the c/e1 epitope of HBcAg(1-149).

The c/e1 epitope (residues 72 to 88) of HBcAg is located in the tip region on the surface of the Hepatitis B virus capsid (HBcAg). A part of this region (Proline 79 and Alanine 80) was genetically replaced by the peptide Gly-Gly-Lys-Gly-Gly (SEQ ID NO: 33), resulting in the HBcAg-Lys construct (SEQ ID NO: 26). The introduced Lysine residue contains a reactive amino group in its side chain that can be used for intermolecular chemical crosslinking of HBcAg particles with any antigen containing a free cysteine group.

HBcAg-Lys DNA, having the amino acid sequence shown in SEQ ID NO:78, was generated by PCRs: The two fragments encoding HBcAg fragments (amino acid residues 1 to 78 and 81 to 149) were amplified separately by PCR. The primers used for these PCRs also introduced a DNA sequence encoding the Gly-Gly-Lys-Gly-Gly

peptide (SEQ ID NO: 33). The HBcAg (1 to 78) fragment was amplified from pEco63 using primers EcoRIHBcAg(s) and Lys-HBcAg(as). The HBcAg (81 to 149) fragment was amplified from pEco63 using primers Lys-HBcAg(s) and HBcAg(1-149)Hind(as). Primers Lys-HBcAg(as) and Lys-HBcAg(s) introduced complementary DNA sequences at the ends of the two PCR products allowing fusion of the two PCR products in a subsequent assembly PCR. The assembled fragments were amplified by PCR using primers EcoRIHBcAg(s) and HbcAg(1-149)Hind(as).

For the PCRs, 100 pmol of each oligo and 50 ng of the template DNAs were used in the 50 ml reaction mixtures with 2 units of Pwo polymerase, 0.1 mM dNTPs and 2 mM MgSO4. For both reactions , temperature cycling was carried out as follows: 94°C for 2 minutes; 30 cycles of 94°C (1 minute), 50°C (1 minute), 72°C (2 minutes).

Primer sequences:

EcoRIHBcAg(s):
(5'-CCGGAATTCATGGACATTGACCCTTATAAAG-3') (SEQ ID NO: 58);

Lys-HBcAg(as):
(5'-CCTAGAGCCACCTTTGCCACCATCTTCTAAATTAG-TACCCACCCAGGTAGC-3') (SEQ ID NO: 59);

Lys-HBcAg(s):
(5'-GAAGATGGTGGCAAAGGTGGCTCTAGGGACC-TAGTAGTCAGTTATGTC -3') (SEQ ID NO: 60);

HBcAg(1-149)Hind(as):
(5'-CGCGTCCCAAGCTTCTAAACAACAGTAGTCTCCGGAAG-3') (SEQ ID NO: 61).

For fusion of the two PCR fragments by PCR 100 pmol of primers EcoRIHBcAg(s) and HBcAg(1-149)Hind(as) were used with 100 ng of the two purified PCR fragments in a 50 ml reaction mixture containing 2 units of Pwo polymerase, 0.1 mM dNTPs and 2 mM $MgSO_4$. PCR cycling conditions were: 94°C for 2 minutes; 30 cycles of 94°C (1 minute), 50°C (1 minute), 72°C (2 minutes). The assembled PCR product was analyzed by agarose gel electrophoresis, purified and digested for 19 hours in an appropriate buffer with EcoRI and HindIII restriction

enzymes. The digested DNA fragment was ligated into EcoRI/HindIII-digested pKK vector to generate pKK-HBcAg-Lys expression vector. Insertion of the PCR product into the vector was analyzed by EcoRI/HindIII restriction analysis and DNA sequencing of the insert.

EXAMPLE 3

Expression and purification of HBcAg-Lys.

E. coli strains K802 or JM109 were transformed with pKK-HBcAg-Lys. 1 ml of an overnight culture of bacteria was used to innoculate 100 ml of LB medium containing 100 µg/ml ampicillin. This culture was grown for 4 hours at 37°C until an OD at 600 nm of approximately 0.8 was reached. Induction of the synthesis of HBcAg-Lys was performed by addition of IPTG to a final concentration of 1 mM. After induction, bacteria were further shaken at 37°C for 4 hours. Bacteria were harvested by centrifugation at 5000 x g for 15 minutes. The pellet was frozen at -80°C. The pellet was thawed and resuspended in bacteria lysis buffer (10 mM Na_2HPO_4, pH 7.0, 30 mM NaCl, 0.25% Tween-20, 10 mM EDTA) supplemented with 200 µg/ml lysozyme and 10 µl of Benzonase (Merck). Cells were incubated for 30 minutes at room temperature and disrupted by sonication. *E. coli* cells harboring pKK-HBcAg-Lys expression plasmid or a control plasmid were used for induction of HBcAg-Lys expression with IPTG. Prior to the addition of IPTG, a sample was removed from the bacteria culture carrying the pKK-HBcAg-Lys plasmid and from a culture carrying the control plasmid. Four hours after addition of IPTG, samples were again removed from the culture containing pKK-HBcAg-Lys and from the control culture. Protein expression was monitored by SDS-PAGE followed by Coomassie staining.

The lysate was then centrifuged for 30 minutes at 12,000 x g in order to remove insoluble cell debris. The supernatant and the pellet were analyzed by Western blotting using a monoclonal antibody against HBcAg (YVS1841, purchased from Accurate Chemical and Scientific Corp., Westbury, NY, USA), indicating that a significant amount of HBcAg-Lys protein was soluble. Briefly, lysates from *E. coli* cells expressing HBcAg-Lys and from control cells were centrifuged at

14,000 x g for 30 minutes. Supernatant (= soluble fraction) and pellet (= insoluble fraction) were separated and diluted with SDS sample buffer to equal volumes. Samples were analyzed by SDS-PAGE followed by Western blotting with anti-HBcAg monoclonal antibody YVS 1841.

The cleared cell lysate was used for step-gradient centrifugation using a sucrose step gradient consisting of a 4 ml 65% sucrose solution overlaid with 3 ml 15% sucrose solution followed by 4 ml of bacterial lysate. The sample was centrifuged for 3 hrs with 100,000 x g at 4°C. After centrifugation, 1 ml fractions from the top of the gradient were collected and analyzed by SDS-PAGE followed by Coomassie staining. The HBcAg-Lys protein was detected by Coomassie staining.

The HBcAg-Lys protein was enriched at the interface between 15 and 65% sucrose indicating that it had formed a capsid particle. Most of the bacterial proteins remained in the sucrose-free upper layer of the gradient, therefore step-gradient centrifugation of the HBcAg-Lys particles led both to enrichment and to a partial purification of the particles.

Expression and purification of HBcAg-Lys in large scale was performed as follows. An overnight culture was prepared by inoculating a single colony in 100 ml LB, 100 µg/ml Ampicillin and growing the culture overnight at 37°C. 25 ml of the preculture were diluted in 800 ml LB Ampicillin medium the next day, and the culture gorwn to an optical density OD^{600} of 0.6-0.8. The culture was then induced with 1 mM IPTG, and left to grow for another 4 hours. The cells were harvested and lysed essentially as described above.

HBcAg-Lys was then purified by first precipitating the protein with ammonium sulphate (30% saturation) from the cleared cell lysate, then loading the resolubilized pellet on a gel filtration column (Sephacryl S-400, Pharmacia). The pooled fractions were precipitated again with ammonium sulphate, the pellet resolubilized and loaded a second time on the same gel filtration column. The fractions were finally pooled and concentrated, and the concentration assessed using a Bradford test (BioRad).

EXAMPLE 4

Construction of a HBcAg devoid of free cysteine residues and containing an inserted lysine residue.

A Hepatitis core Antigen (HBcAg), referred to herein as HBcAg-lys-2cys-Mut, devoid of cysteine residues at positions corresponding to 48 and 107 in SEQ ID NO:25 and containing an inserted lysine residue was constructed using the following methods.

The two mutations were introduced by first separately amplifying three fragments of the HBcAg-Lys gene prepared as described above in Example 2 with the following PCR primer combinations. PCR methods and conventional cloning techniques were used to prepare the HBcAg-lys-2cys-Mut gene.

In brief, the following primers were used to prepare fragment 1:

Primer 1: EcoRIHBcAg(s)

CCGGAATTCATGGACATTGACCCTTATAAAG (SEQ ID NO: 58)

Primer 2: 48as

GTGCAGTATGGTGAGGTGAGGAATGCTCAGGAGACTC (SEQ ID NO: 62)

The following primers were used to prepare fragment 2:

Primer 3: 48s

GSGTCTCCTGAGCATTCCTCACCTCACCATACTGCAC (SEQ ID NO: 63)

Primer 4: 107as

CTTCCAAAAGTGAGGGAAGAAATGTGAAACCAC (SEQ ID NO: 64)

The following primers were used to prepare fragment 3:

Primer 5: HBcAg149hind-as

CGCGTCCCAAGCTTCTAAACAACAGTAGTCTCCGGAAGC-GTTGATAG (SEQ ID NO: 65)

Primer 6: 107s

GTGGTTTCACATTTCTTCCCTCACTTTTGGAAG (SEQ ID NO: 66)

Fragments 1 and 2 were then combined with PCR primers EcoRIHBcAg(s) and 107as to give fragment 4. Fragment 4 and fragment 3 were then combined with

primers EcoRIHBcAg(s) and HBcAg149hind-as to produce the full length gene. The full length gene was then digested with the EcoRI (GAATTC) and HindIII (AAGCTT) enzymes and cloned into the pKK vector (Pharmacia) cut at the same restriction sites. Expression and purification of HBcAg-lys-2cys-Mut were performed as set out in Example 3.

EXAMPLE 5

Construction of HBcAg1-185-Lys.

Hepatitis core Antigen (HBcAg) 1-185 was modified as described in Example 2. A part of the c/e1 epitope (residues 72 to 88) region (Proline 79 and Alanine 80) was genetically replaced by the peptide Gly-Gly-Lys-Gly-Gly (SEQ ID NO: 33), resulting in the HBcAg-Lys construct (SEQ ID NO: 26). The introduced Lysine residue contains a reactive amino group in its side chain that can be used for intermolecular chemical crosslinking of HBcAg particles with any antigen containing a free cysteine group. PCR methods and conventional cloning techniques were used to prepare the HBcAg1-185-Lys gene.

The Gly-Gly-Lys-Gly-Gly sequence (SEQ ID NO: 33) was inserted by amplifying two separate fragments of the HBcAg gene from pEco63, as described above in Example 2 and subsequently fusing the two fragments by PCR to assemble the full length gene. The following PCR primer combinations were used:

fragment 1:

Primer 1: EcoRIHBcAg(s) (SEQ ID NO: 58) (see Example 2)

Primer 2: Lys-HBcAg(as) (SEQ ID NO: 59) (see Example 2)

fragment 2:

Primer 3: Lys-HBcAg(s) (SEQ ID NO: 60) (see Example 2)

Primer 4: HBcAgwtHindIIII

CGCGTCCCAAGCTTCTAACATTGAGATTCCCGAGATTG (SEQ ID NO: 67)

Assembly:

Primer 1: EcoRIHBcAg(s) (SEQ ID NO: 58) (see example 2)

Primer 2: HBcAgwtHindIIII (SEQ ID NO: 67)

The assembled full length gene was then digested with the EcoRI (GAATTC) and HindIII (AAGCTT) enzymes and cloned into the pKK vector (Pharmacia) cut at the same restriction sites.

EXAMPLE 6

Fusion of a peptide epitope in the MIR region of HbcAg.

The residues 79 and 80 of HBcAg1-185 were substituted with the epitope CεH3 of sequence VNLTWSRASG (SEQ ID NO: 68). The CεH3 sequence stems from the sequence of the third constant domain of the heavy chain of human IgE. The epitope was inserted in the HBcAg1-185 sequence using an assembly PCR method. In the first PCR step, the HBcAg1-185 gene originating from ATCC clone pEco63 and amplified with primers HBcAg-wt EcoRI fwd and HBcAg-wt Hind III rev was used as template in two separate reactions to amplify two fragments containing sequence elements coding for the CεH3 sequence. These two fragments were then assembled in a second PCR step, in an assembly PCR reaction.

Primer combinations in the first PCR step: CεH3fwd with HBcAg-wt Hind III rev, and HBcAg-wt EcoRI fwd with CεH3rev. In the assembly PCR reaction, the two fragments isolated in the first PCR step were first assembled during 3 PCR cycles without outer primers, which were added afterwards to the reaction mixture for the next 25 cycles. Outer primers: HBcAg-wt EcoRI fwd and HBcAg-wt Hind III rev.

The PCR product was cloned in the pKK223.3 using the EcoRI and HindIII sites, for expression in E. coli (see Example 2). The chimeric VLP was expressed in *E. coli* and purified as described in Example 2. The elution volume at which the HBcAg1-185- CεH3 eluted from the gel filtration showed assembly of the fusion proteins to a chimeric VLP.

Primer sequences:

CεH3fwd:

5′*GTT AAC TTG ACC TGG TCT CGT GCT TCT GGT* GCA TCC AGG GAT CTA GTA GTC 3′

(SEQ ID NO: 69)

V N L T W S R A S G A80 S R D L V V86

(SEQ ID NO: 70)

CεH3rev:

5′ *ACC AGA AGC ACG AGA CCA GGT CAA GTT AAC* ATC TTC CAA ATT ATT ACC CAC 3′

(SEQ ID NO: 71)

D78 E L N N G V72

(SEQ ID NO: 72)

HBcAg-wt EcoRI fwd:

5' *CCG*gaattcATGGACATTGACCCTTATAAAG (SEQ ID NO: 73)

HBcAg-wt Hind III rev:

5' *CGCGTCC*CaagcttCTAACATTGAGATTCCCGAGATTG (SEQ ID NO: 74)

EXAMPLE 7

Fusion of Aβ1-6 peptide in the MIR region of HbcAg.

The residues 79 and 80 of HBcAg1-185 are substituted with the Aβ1-6 peptide of sequence: DAEFRH (SEQ ID NO: 75) or DAEFGH (SEQ ID NO: 76). Two overlapping primers are designed using the same strategy described in Example 6, and the fusion protein constructed by assembly PCR. The PCR product is cloned in the pKK223.3 vector, and expressed in E. coli K802. The chimeric VLPs are expressed and purified as described in Example 3.

EXAMPLE 8

Fusion of a Aβ1-6 peptide to the C-terminus of the Qβ A1 protein truncated at position 19 of the CP extension.

A primer annealing to the 5' end of the Qβ A1 gene and a primer annealing to the 3' end of the A1 gene and comprising additionally a sequence element coding for the Aβ1-6 peptide, of sequence DAEFRH (SEQ ID NO: 75) or DAEFGH (SEQ ID NO: 76), are used in a PCR reaction with pQβ10 as template. The PCR product is cloned in pQβ10 (Kozlovska T.M. *et al., Gene 137*: 133-37 (1993)), and the chimeric VLP expressed and purified as described in Example 1.

EXAMPLE 9

Insertion of a Aβ1-6 peptide between positions 2 and 3 of fr coat protein.

Complementary primers coding for the sequence of the Aβ1-6 peptide of sequence DAEFRH (SEQ ID NO: 75) or DAEFGH (SEQ ID NO: 76), and containing *Bsp119*I compatible ends and additional nucleotides enabling in frame insertion, are inserted in the Bsp119I site of the pFrd8 vector (Pushko, P. *et al., Prot. Eng. 6*: 883-91 (1993)) by standard molecular biology techniques. Alternatively, the overhangs of the pFrd8 vector are filled in with Klenow after digestion with *Bsp119*I, and oligonucleotides coding for the sequence of the Aβ1-6 peptide and additional nucleotides for in frame cloning are ligated in pFrd8 after the Klenow treatment. Clones with the insert in the right orientation are analysed by sequencing. Expression and purification of the chimeric fusion protein in E. coli JM109 or E. coli K802 is performed as described in Pushko, P. *et al, Prot. Eng. 6*:883-91 (1993), but for the chromatography steps which are performed using a Sepharose CL-4B or Sephacryl S-400 (Pharmacia) column. The cell lysate is precipitated with ammonium sulphate, and purified by two successive gel filtration purification steps, similarly to the procedure described for Qβ in Example 1.

EXAMPLE 10

Insertion of a Aβ1-6 peptide between positions 67 and 68 of Ty1 protein p1 in the vector pOGS8111.

Two complementary oligonucleotides coding for the Aβ1-6 peptide, of sequence DAEFRH (SEQ ID NO: 75) or DAEFGH (SEQ ID NO: 76), with ends compatible with the NheI site of pOGS8111 are synthesized. Additional nucleotides are added to allow for in frame insertion of a sequence coding for the Aβ1-6 peptide according to the description of EP 677'111. The amino acids AS and SS flanking the inserted epitope are encoded by the altered NheI sites resulting from the insertion of the oligonucleotide in the TyA(d) gene of pOGS8111.

POGS8111 is transformed into *S. cervisiae* strain MC2, for expression of the chimeric Ty VLP as described in EP0677111 and references therein. The chimeric Ty VLP is purified by sucrose gradient ultracentrifugation as described in EP 677'111.

EXAMPLE 11

Insertion of a Aβ1-6 peptide into the major capsid protein L1 of papillomavirus type 1 (BPV-1).

A sequence coding for the Aβ1-6 peptide having the sequence DAEFRH (SEQ ID NO: 75) or DAEFGH (SEQ ID NO: 76) is substituted to the sequence coding for amino acids 130-136 of the BPV-1 L1 gene cloned in the pFastBac1 (GIBCO/BRL) vector as described (Chackerian, B. *et al., Proc. Natl. Acad.* USA 96: 2373-2378 (1999)). The sequence of the construct is verified by nucleotide sequence analysis. Recombinant baculovirus is generated using the GIBCO/BRL baculovirus system as described by the manufacturer. The chimeric VLPs are purified from baculovirus infected Sf9 cells as described by Kirnbauer, R. et al., Proc. Natl. Acad. Sci. 89:12180-84 (1992) and Greenstone, H.L., et al., Proc. Natl. Acad. Sci. 95:1800-05 (1998).

EXAMPLE 12

Immunization of mice with Aβ1-6 peptide fused to VLPs.

Chimeric VLPs displaying the Aβ1-6 peptide of sequence DAEFRH (SEQ ID NO: 75) or DAEFGH (SEQ ID NO: 76) generated in Examples 7-11 are used for immunization of human transgenic APP mice or C57/BL6 mice as described in Example 13 and 14. The sera obtained from the immunized mice are analysed in a Aβ1-6 peptide or Aβ1-40 or Aβ1-42 specific ELISA as described in Example 13.

The protective effect of the vaccine is examined by immunizing a large group of human APP transgenic mice as described in Example 14.

EXAMPLE 13

Coupling of Aβ1-6 peptide to Qβ VLP (QβAβ1-6), and immunization of mice with QβAβ1-6

A. Coupling of Aβ1-6 peptide Qβ VLP

The Aβ1-6 peptide (sequence: NH2-DAEFRHGGC-CONH2) (SEQ ID NO: 77) was chemically synthesized; the initial NH2 group indicates that the peptide has a free N-terminus, and the terminal NH2 group indicates that the peptide has an amidated carboxy-terminus. Qβ VLP was expressed and purified as described in example 1. Qβ VLP, in 20 mM Hepes, 150 mM NaCl, pH 8.2 (HBS, pH 8.2) was reacted at a concentration of 2 mg/ml (determined in a Bradford assay), with 1.43 mM SMPH (Pierce, Rockford IL), diluted from a stock in DMSO, for 30 minutes at room temperature (RT). The reaction mixture was then dialyzed against HBS, pH 8.2 buffer at 4°C, and reacted with 0.36 mM of Aβ1-6 peptide, diluted in the reaction mixture from a 50 mM stock in DMSO. The coupling reaction was left to proceed for 2 hours at 15°C, and the reaction mixture dialyzed 2 X 2 hours against a 1000-fold volume HBS, pH 8.2, and flash frozen in liquid nitrogen in aliquots for storage at -80°C until further use.

An aliquot was thawed, and coupling of the Aβ1-6 peptide to the Qβ VLP subunits assessed by SDS-PAGE and the protein concentration measured in a Bradford assay. The result of the coupling reactions are shown in FIG. 1.

FIG. 1 shows the SDS-PAGE analysis of the coupling reaction of Aβ1-6 peptide and Qβ VLP. The samples were run under reducing conditions on a 16% Tris-glycine gel, stained with coomassie brilliant blue. Lane 1 is the protein marker, with corresponding molecular weights indicated on the left border of the gel; lane 2, derivatized Qβ VLP protein; lane 3, the supernatant of the coupling reaction of Qβ VLP protein to the Aβ1-6 peptide; lane 4, the pellet of the coupling reaction of Qβ VLP protein to the Aβ1-6 peptide; Coupling products corresponding to the coupling of 1, 2 and 3 peptides per monomer are indicated by arrows in the Figure. More than 1.5 peptides per subunit were coupled on average; nearly no subunits were left uncoupled.

B. Immunisation of mice with Aβ1-6 peptide coupled to Qβ VLP and analysis of immune response

Qβ VLP coupled to Aβ1-6 peptide (denominated here Qb-Ab-1-6) was injected s.c. in mice (3 mice) at day 0 and 14. Aβ1-6 peptide was coupled to Qβ VLP protein as described above. Each mice (C57BL/6) was immunized with 10 μg of vaccine diluted in PBS to 200 μl. Mice were retroorbitally bled on day 21, and the titer of the antibodies specific for the Aβ1-6 peptide were measured in an ELISA against Aβ1-6. The Aβ1-6 peptide was coupled to bovine RNAse A using the chemical cross-linker sulfo-SPDP. ELISA plates were coated with coupled RNAse preparations at a concentration of 10 μg/ml. The plates were blocked and then incubated with serially diluted mouse sera. Bound antibodies were detected with enzymatically labeled anti-mouse IgG antibodies. As a control, preimmune sera of the same mice were also tested. The results are shown in FIG. 2.

FIG. 2 shows an ELISA analysis of the IgG antibodies specific for Aβ1-6 peptide in sera of mice immunized against the Aβ1-6 peptide coupled to Qβ VLP. The results are shown for the three mice immunized (A1-A3), the pre-immune serum is indicated as "pre" in the figure; the result for one pre-immune serum is shown.

Comparison of the pre-immune sera with the sera of mice immunized with "Qb-Ab-1-6" shows that a strong specific antibody response against peptide Aβ1-6 could be obtained in the absence of adjuvant.

C. ELISA against Aβ 1-40 peptide

Human Aβ 1-40 or Aβ 1-42 peptide stock was made in DMSO and diluted in coating buffer before use. ELISA plates were coated with 0.1 μg /well Aβ 1-40 peptide. The plates were blocked and then incubated with serially diluted mouse serum obtained above. Bound antibodies were detected with enzymatically labeled anti-mouse IgG antibody. As a control, sera obtained before vaccination were also included. The serum dilution showing a mean three standard deviations above baseline was calculated and defined as "ELISA titer". No specific antibodies were detected in preimmune sera. The titer obtained for the three mice was of 1:100000, showing a strong specific immune response against Aβ 1-40. Thus, immunization with Aβ1-6 coupled to Qβ VLP elicits strong antibody titers cross-reactive with Aβ1-40.

FIG. 3 shows the result of the ELISA. The ELISA signal as the optical density at 405 nm, obtained for the sera of three mice (A1-A3) immunized with Aβ1-6 peptide coupled to Qβ VLP as described above, is plotted for each of the dilutions, indicated on the x-axis. The result for the three mice bled at day 21 is shown. Also included is a pre-immune serum. The titer of the antibodies in the sera was determined as described above, and was of 1:100000 for all three mice.

EXAMPLE 14

Immunization of human APP transgenic mice

8 months old female APP23 mice which carry a human APP transgene (Sturchler-Pierrat *et al., Proc.Natl. Acad.Sci. USA 94*: 13287-13292 (1997)) are used for vaccination. The mice are injected subcutaneously with 25 μg vaccine diluted in sterile PBS and 14 days later boosted with the same amount of vaccine. Mice are bled from the tail vein before the start of immunization and 7 days after the booster

injection. The sera are analyzed for the presence of antibodies specific to a Aβ1-6, to Aβ1-40 and Aβ1-42 by ELISA as described in Example 13.

EXAMPLE 15

Coupling of murine Aβ1-6 to Qβ VLP, injection of the vaccine in mice, and analysis of the immune response

Murine Aβ1-6 peptide (sequence: NH2-DAEFGHGGC-CONH2) (SEQ ID NO: 78) is chemically synthesized, and used for coupling to Qβ VLP as described in Example 13. The vaccine is injected in C57BL/6 mice, and the titer of the elicited antibodies against murine Aβ1-6, murine Aβ1-40 and murine Aβ1-42 determined. The immunization and the ELISA determination are performed as described in Example 13.

EXAMPLE 16

Binding of sera elicited against Aβ1-6 to human APP transgenic mice plaques and AD plaques

Immunohistochemistry in brain slices

Consecutive paraffin brain sections of a 18 months, old heterozygous APP23 mouse and entorhinal cortex sections from an AD patient Braak Stage III (Institute of Pathology, University Basel) were used for staining. Antigenicity was enhanced by treating human brain sections with concentrated formic acid for five minutes and mouse brain sections by microwave heating at 90 °C for 3 minutes. Mice sera elicited against human Aβ1-6 (obtained as described in Example 13) were diluted 1:1000 in PBS with 3% goat serum and incubated over night. Following rinsing, sections were incubated for 1 hour with biotinylated anti mouse secondary antibody diluted 1:200 in PBS. After rinsing, sections were further processed with the avidin-biotin-peroxidase technique (ABC-Elite Kit PK6100; Vector Laboratories). Finally, sections were reacted with Diaminobenzidine (DAB) metal enhanced substrate (Boehringer, Code 1718096), counterstaind with Hemalum, dehydrated, cleared in Xylene and coversliped.

The result of the histologic stains are shown in FIG. 4 A and B. Sections were stained with the sera of the three mice immunized against human Aβ1-6 coupled to Qβ VLP. Each serum stained positively the amyloid plaques from transgenic mice and AD. Results for one of the three sera are shown. Sera elicited against human Aβ1-6 clearly stain amyloid plaques of the transgenic human APP23 mouse, as well as amyloid plaques from AD patients. Pre-immune sera were negative. Extracellular amyloid plaques and isolated blood vessels are stained by the antibodies.

EXAMPLE 17

Specificity of sera elicited against human Aβ1-6, assessed by histology of mice plaques

Immunohistochemistry in brain slices

Consecutive paraffin brain sections of a 3 months and an 18 months old heterozygous APP23 mouse overexpressing human APP were stained as described in Example 16 with a representative mouse serum elicited against human Aβ1-6 as described in Example 13, or with a rabbit polyclonal antibody specific for the last 20 amino acids of murine or human APP and which therefore does not recognizes Aβ. The sections incubated with the rabbit polyclonal antibody were treated as described in Example 16, except for the use of a biotinylated anti rabbit secondary antibody (BA1000, Vector Laboratories).

The result of the histologic stains are shown on FIG. 5 A, B, C, D and E. Aβ1-6, marked on the bottom left of the sections indicate that sera elicited against Aβ1-6 have been used for the staining, while "Pab" indicates that the sections have been stained with the polyclonal antibody specific for the last 20 amino acids of murine or human APP, corresponding to positions 676-695 in APP_{695}.

Comparison of the staining of sections from 18 months old mice (FIG. 5 A and C) shows that the sera elicited against Aβ1-6 do not cross-react with APP expressed in the brain, which is however stained by the control polyclonal antibody. FIG. 5 B shows a brain section from a 3 months old mouse, a timepoint where amyloid deposits are not yet visible, stained with the polyclonal antibody specific for APP.

FIG. 5 D and 5E show a magnification of the CA1 pyramidal layer of the hippocampus from FIG. 5A. and FIG. 5B, respectively.

EXAMPLE 18

A. Coupling of Aβ1-6 peptide to fr capsid protein

A solution of 120 μM fr capsid protein in 20 mM Hepes, 150 mM NaCl pH 7.2 is reacted for 30 minutes with a 10 fold molar excess of SMPH (Pierce), diluted from a stock solution in DMSO, at 25 °C on a rocking shaker. The reaction solution is subsequently dialyzed twice for 2 hours against 1 L of 20 mM Hepes, 150 mM NaCl, pH 7.2 at 4 °C. The dialyzed fr reaction mixture is then reacted with a a five-fold molar excess of Aβ1-6 peptide (sequence: NH2-DAEFRHGGC-CONH2) (SEQ ID NO: 77) for 2 hours at 16 °C on a rocking shaker. Coupling products are analysed by SDS-PAGE.

B. Coupling of Aβ1-6 peptide to HBcAg-Lys-2cys-Mut

A solution of 1 ml of 120 μM HBcAg-Lys-2cys-Mut in 20 mM Hepes, 150 mM NaCl pH 7.2 is reacted for 30 minutes with a 10 fold molar excess of SMPH (Pierce), diluted from a stock solution in DMSO, at 25 °C on a rocking shaker. The reaction solution is subsequently dialyzed twice for 2 hours against 1 L of 20 mM Hepes, 150 mM NaCl, pH 7.2 at 4 °C. The dialyzed HBcAg-Lys-2cys-Mut reaction mixture is then reacted with a five-fold molar excess of Aβ1-6 peptide (sequence: NH2-DAEFRHGGC-CONH2) (SEQ ID NO: 77) for 2 hours at 16 °C on a rocking shaker. Coupling products are analysed by SDS-PAGE.

C. Coupling of Aβ1-6 peptide to Pili

A solution of 125 μM Type-1 pili of *E.coli* in 20 mM Hepes, pH 7.4, is reacted for 60 minutes with a 50-fold molar excess of cross-linker SMPH (Pierce), diluted from a stock solution in DMSO, at RT on a rocking shaker. The reaction mixture is desalted on a PD-10 column (Amersham-Pharmacia Biotech). The protein-containing

fractions eluating from the column are pooled, and the desalted derivatized pili protein is reacted with a five-fold molar excess of Aβ1-6 peptide (sequence: NH2-DAEFRHGGC-CONH2) (SEQ ID NO: 77) for 2 hours at 16 °C on a rocking shaker. Coupling products are analysed by SDS-PAGE.

D. Immunization of mice with Aβ1-6 peptide coupled to fr-capsid protein, HBcAg-Lys-2cys-Mut or pili

Aβ1-6 peptide coupled to fr-capsid protein, HBcAg-Lys-2cys-Mut or pili as described above is injected s.c. in mice (3 mice) at day 0 and 14. Each mice (C57BL/6) is immunized with 10 µg of vaccine diluted in PBS to 200 µl. Mice are retroorbitally bled on day 21, and the titer of the antibodies specific for the Aβ1-6 peptide or Aβ1-40 or Aβ1-42 are measured by ELISA as described in Example 13.

EXAMPLE 19

Immunisation of rhesus monkeys with QβhAβ1-6

In order to test induction of antibodies against human Aβ using a human Aβ1-6 peptide based vaccine in the case where Aβ1-6 is a self antigen, rhesus monkeys were immunized with QβhAβ1-6, as the Aβ sequence is identical between humans and Rhesus monkeys. QβhAβ1-6 vaccine was made as described in Example 13. Four Rhesus monkeys, between 10 and 15 years of age, were immunized at day 0 with 50 µg of vaccine, and boosted twice at day 28 and 56 with 25 µg of vaccine. The monkeys were immunized subcutaneously in the back. The animals were bled at day 0 (prebleed), 42 and 70. 4 ml of blood were collected from the V. cephalica antebrachii. The titer of antibodies specific for Aβ1-40 were measured by ELISA essentially as described in Example 13, using a secondary antibody specific for Monkey IgG.

As humans and rhesus monkeys share the same Aβ sequence, the generation of high titer antibodies in rhesus monkeys specific for Aβ1-40 shows that immunization with hAβ1-6 coupled to Qβ breaks tolerance against the self-antigen Aβ.

Furthermore, antibodies recognizing full length Aβ are generated with the coupled Aβ1-6 fragment in primates.

The results of the ELISA are shown in Fig. 6. Plotted in the diagram are the titers of Aβ1-40 specific antibodies measured in the sera of the 4 monkeys (1-4) immunized with QβhAβ1-6 and the average of the titers of the 4 monkeys. The titers are represented as OD50 titers. OD50 is the dilution of the antibodies at which the signal reaches half of its maximal value. The maximal value (OD max) was obtained from a reference serum originating from a monkey immunised with QβhAβ1-27 and recognizing Aβ1-40 as well, and measured on the same ELISA plate.

Two monkeys (described above) were bled at day 97, 110, 117, 124, 138, 143, 152, 159, 166, and received a third boost with 25 µg of vaccine at day 110. Sera were pooled (99 ml) and used for affinity purification of Aβ1-6-specific antibodies. These antibodies were used for immunohistochemical staining at a concentration of 1.5 µg/ml and a biotinylated secondary anti-monkey antibody was used for detection. Paraffine brain sections of 18 months old heterozygous APP23 mouse and an AD patient – Braak Stage III – were used for staining. Plaque-specific staininig was observed both in APP23 mouse brain sections and in the AD patient brain sections (Fig. 7).

The result of the histological analysis is shown in Fig. 7 A and B. Depicted in Fig. 7 A is the staining of human APP transgenic mouse plaques (APP23 strain) with the above described affinity purified antiserum specific for Aβ1-6. Fig. 7 B shows the staining of human AD plaques with the same purified antiserum. The purified antiserum was used at a concentration of 1.5 µg/ml in both cases. Typical plaques are indicated by an arrow on both figures.

EXAMPLE 20

Coupling of murine Aβ1-6 to AP205 VLP, immunisation of mice and analysis of immune response

A. Coupling of murine Aβ1-6 peptide to AP205 VLP

The peptide murine Aβ1-6 (mAβ1-6, sequence: NH2-DAEFGHGGC-CONH2 (SEQ ID NO: 78) was chemically synthesized; the initial NH2 group indicates that the peptide has a free N-terminus, and the terminal NH2 group indicates that the peptide has an amidated carboxy-terminus). AP205 VLP (expressed and purified as described in Example 1), in 20 mM Hepes, 150 mM NaCl, pH 8.0 (HBS, pH 8.0) was reacted at a concentration of 2 mg/ml (determined in a Bradford assay), with 2.86 mM SMPH (Pierce, Rockford IL), diluted from a 100 mM stock in DMSO, for 30 minutes at room temperature (RT). The reaction mixture was then dialyzed twice against a 1000-fold volume of HBS, pH 7.4. at 4°C for two hours; the resulting dialyzed and derivatized AP205 VLP was flash frozen in liquid nitrogen and stored at -20°C overnight. Derivatized AP205 VLP was diluted with one volume of 20 mM HBS, pH 7.4, and reacted 2 hours at 15°C under shaking with 719 µM mAβ1-6 peptide diluted in the reaction mixture from a 50 mM stock in DMSO. The coupling reaction was dialyzed twice against a 1000-fold volume HBS, pH 7.4, for 2 hours and overnight. The dialyzed reaction mixture was flash frozen in liquid nitrogen in aliquots for storage at -80°C until further use.

An aliquot was thawed, and coupling of the mAβ1-6 peptide to the AP205 VLP subunits assessed by SDS-PAGE and the protein concentration measured in a Bradford assay. The result of the coupling reaction is shown in FIG. 8.

FIG. 8 shows the SDS-PAGE analysis of the coupling reaction of mAβ1-6 peptide to AP205 VLP. The samples were run under reducing conditions on a 16% Tris-glycine gel and stained with coomassie brilliant blue. Lane 1 is the protein marker, with corresponding molecular weights indicated on the left border of the gel; lane 2, AP205 VLP protein; lane 3, derivatized AP205 VLP; lane4, the supernatant of the coupling reaction of AP205 VLP to mAβ1-6 peptide; lane 5, the pellet of the coupling reaction of AP205 VLP to mAβ1-6 peptide. No AP205 VLP subunits left

uncoupled could be detected on the gel, while bands corresponding to several peptides per subunits were visible, demonstrating a very high coupling efficiency. In particular, there is much more than one Aβ1-6 peptide per AP205 VLP subunit.

B. Immunisation of mice with mAβ1-6 peptide coupled to AP205 VLP and analysis of immune response

AP205 VLP coupled to mAβ1-6 peptide was injected s.c. in mice (3 mice) at day 0 and 14. mAβ1-6 peptide was coupled to AP205 VLP as described above. Each mice (C57BL/6) was immunized with 25 μg of vaccine diluted in PBS to 200 μl. Mice were retroorbitally bled on day 21, and the titer of the antibodies specific for the mAβ1-6 peptide were measured in an ELISA against mAβ1-6. The mAβ1-6 peptide was coupled to bovine RNAse A using the chemical cross-linker sulfo-SPDP. ELISA plates were coated with preparations of RNAse-mAβ1-6 at a concentration of 10 μg/ml. The plates were blocked and then incubated with serially diluted mouse sera. Bound antibodies were detected with enzymatically labeled anti-mouse IgG antibodies. As a control, preimmune sera of the same mice were also tested. The results are shown in FIG. 9.

FIG. 9 shows an ELISA analysis of the IgG antibodies specific for mAβ1-6 peptide in sera of mice immunized with the mAβ1-6 peptide coupled to AP205 VLP. The results are shown for the sera of the three immunized mice collected at day 21 (A1 d21 -A3 d21), the pre-immune serum is indicated as "pre imm" in the figure; the result for one pre-immune serum is shown. Comparison of the pre-immune serum with the sera of the mice immunized with mAβ1-6 coupled to AP205 VLP shows that a strong specific antibody response against peptide mAβ1-6, which is a self-antigen, could be obtained in the absence of adjuvant. Furthermore, coupling of a self-peptide to AP205 VLP leads to break of tolerance against this peptide, and to a very high specific immune response. Thus, AP205 VLP is suitable for generating high antibody titers against Aβ peptides in the absence of adjuvant.

EXAMPLE 21

Immunisation with QβhAβ1-6 reduces amyloid plaques in transgenic mice over-expressing the "Swedish/London" mutant amyloid precursor protein

This example demonstrates that immunization with QβhAβ1-6 in a mouse model developing Alzheimer's disease-like diffuse (Congo-Red negative) amyloid plaques, resulted in a massive reduction of plaque density in neocortical and subcortical brain areas. Histological occurrence of diffuse amyloid plaques is a prominent feature of AD brain pathology (Selkoe, 1994, Annu. Rev. Neurosci. 17:489-517) and, therefore, the example demonstrates that immunization with QβhAβ1-6 provides an effective approach for the treatment of Alzheimer's disease.

To evaluate the therapeutic efficacy of immunization with Qβ-Aβ1-6 transgenic mice over-expressing the "Swedish/London" mutant amyloid precursor protein under the control of the mouse Thy-1 promoter (APP24; K670N/M671L; V717I, patent No. WO980-36-4423) were used. This mouse strain is characterized by a large number amyloid plaques in the neocortex, hippocampus, caudate putamen, and thalamus at an age of 18 months. Plaques can be first observed at an age of 9 months. Histologically, the amyloid plaques in APP24 mice are predominantly of a diffuse type, i.e. they are negative in Congo-Red staining. To a lesser degree, also compact amyloid plaques (Congo-Red positive) can be found.

Human Aβ1-6 peptide coupled to Qβ VLP (QβhAβ1-6) was made as described in Example 13. In terms of the experimental procedure followed, which is not necessary for describing or enabling the invention, APP24 transgenic mice 9.5 months of age were injected subcutaneously at day 0 with 25 µg of QβhAβ1-6 in phosphate-buffered saline (PBS) (administered as 2x100 µl per mouse) (n=16) or as negative controls with PBS (administered as 2x100 µl per mouse) (n=9) or with Qβ virus-like particle devoid of coupled antigen (n=11). Mice were subsequently injected 25 µg of QβhAβ1-6-vaccine, Qβ, or PBS on day 15, 49, 76, 106, 140, 169, 200, 230, 259, and 291. Animals were bled 1-2 days before the first immunization (day 0) and on day 56, 90, 118, 188, 214, 246, and 272 via the tail vein. Blood serum was also collected on day 305, at which time also brains were collected for histopathology (age of the mice at this time point: 19.5 months).

The titer of antibodies specific for Aβ1-40 were measured by ELISA essentially as described in Example 13. The results of the ELISA are shown in Fig. 10. Plotted in the diagram are the titers of Aβ1-40 or Aβ1-42 specific antibodies measured in the sera of mice immunized with QβhAβ1-6. The titers are represented as OD50% titers. OD50% is the dilution of the antibodies at which the signal reaches half of its maximal value. The maximal value (OD max) was obtained from a reference antibody recognizing Aβ1-40 and Ab42, and measured on the same ELISA plate. All QβhAβ1-6 immunized mice developed OD50% titers above 1:8000 (pre-immune serum titers were below 1:100) demonstrating a consistent antibody response to QβhAβ1-6 even in old APP24 mice (Fig. 10). Median OD50% titers in the immunized group were in the range of 1:20'000 to 1:50'000 throughout the immunization period.

For quantification of amyloid plaques, brains were fixed by immersion in 4% formaldehyde in 0.1 M PBS at 4°C. After dehydration with ethanol, brains were embedded in paraffin and cut sagitally with a microtome at 4 µm thickness. Sections were mounted onto super frost slides and dried at 37°C. Sections were washed in PBS and antigenicity enhanced by microwave heating at 90°C for 3 minutes in 0.1 M citric acid buffer. NT11 antisera (anti Aß1-40, Sturchler-Pierrat et al., 1997, Proc. Natl. Acad. Sci. 94: 13287-13292) were diluted 1:1000 in PBS with 3% goat serum and incubated over night at 4°C. Following rinsing, sections were incubated for 1 hour with biotinylated anti rabbit IgG secondary antibody (BA1000, Vector Laboratories) diluted 1:200 in PBS. After rinsing, sections were further processed with the avidin-biotin-peroxidase technique (ABC-Elite Kit PK6100; Vector Laboratories). Finally, sections were reacted with Diaminobenzidine (DAB) metal enhanced substrate (Boehringer, Code 1718096), counterstained with Hemalum, dehydrated, cleared in Xylene and cover slipped. Systematic-random series of brain sections at three different anatomical planes per animal were used for the analysis. Amyloid plaques were quantified using an MCID image analyzer (Imaging Research, Brock University, Ontario-Canada, Program Version M5 elite). The microscopic image was digitized by use of a Xillix black and white CCD TV camera and stored with 640x480 pixel resolution at 256 gray levels. The pixel size was calibrated using an object micrometer at 5x magnification (Leica Neoplan Objective). Using a motor

driven microscope stage for exact positioning of adjacent object fields the entire neocortex and olfactory nucleus of each section was analysed. For each object field the anatomical area was defined by manual outline. For each individual section the sample area was defined by manual threshold setting (grey level) between immunopositive amyloid plaques and tissue background. Isolated tissue artifacts were excluded by manual outline. Raw data are measured as individual counts (amyloid deposits) and proportional area values (immunopositive amyloid/cortex or olfactory nucleus).

Data of each mouse were normalized to number of deposits (plaques) per mm^2 and total plaque area in % of the entire neocortex. QβhAβ1-6 immunized mice revealed a dramatic reduction of amyloid deposits in the cortex and subcortical areas as compared to either PBS or Qβ injected control groups (Fig. 11). Both the median number of deposits and the total plaque area were highly significantly reduced between 80-98 % compared to the PBS group in the cortex, caudate putamen, hippocampus, and thalamus ($p< 0.001$ vs. PBS-group, Mann-Whitney test; Fig. 12).

In a second study, APP24 transgenic mice 13.5 months of age were injected subcutaneously at day 0 with 25 µg of QβhAβ1-6 in phosphate-buffered saline (PBS) (administered as 2x100 µl per mouse) (n=15) or as negative controls with PBS (administered as 2x100 µl per mouse) (n=15). Mice were subsequently injected 25 µg of QβhAβ1-6-vaccine, or PBS on day 16, 46, 76, 109, 140, and 170. Animals were bled 1-2 days before the first immunization (day 0) and on day 31, 59, 128, and 154 via the tail vein. Blood serum was also collected on day 184, at which time also brains were collected for histopathology (age of the mice at this time point: 19.5 months). The titer of antibodies specific for Aβ1-40 were determined and expressed as described above and again all immunized mice were found to respond to QβhAβ1-6 immunization with serum OD50% titers at least above 1:2000 (not shown). Median OD50% titers were in the range of 1:10'000 to 1:50'000 throughout the immunization period. Quantification of amyloid deposits was done as described above. Compared to the experiment where immunization was initiated earlier (i.e. at an age of 9.5 months) the reduction of plaque deposit number (-55 %) and area (- 32 %) was less dramatic in the neocortex, but still very pronounced (Fig. 13) and highly significant ($p>0.001$ vs. PBS, Mann-Whitney test). In subcortical areas plaque

deposit number and area were reduced by 60-90 % in the to QβhAβ1-6 immunized group. The more pronounced effect in these areas as compared to the cortex is probably related to the more protracted time course of plaque formation in these areas.

Taken together, both experiments demonstrate that QβhAβ1-6 immunization in transgenic mice over-expressing the "Swedish/London" mutant amyloid precursor protein dramatically reduces the occurrence of amyloid deposits in these mice.

Figure 10: Serum anti Aβ40/42 antibody titers (OD50%) in transgenic mice over-expressing the "Swedish/London" mutant amyloid precursor protein. Mice were immunized with QβhAβ1-6 between 9.5 and 19 months of age. Shown are individual values (black dots) and box plots, where the ends of the boxes define the 25th and 75th percentiles, with a line at the median and error bars defining the 10th and 90th percentiles (outlyers are shown as dots).

Figure 11: Immunhistochemical staining of amyloid plaques in sagittal brain sections. The sagittal brain section of a transgenic mouse over-expressing the "Swedish/London" mutant amyloid precursor protein immunized with Qβ (A) or QβhAβ1-6 (B) vaccine is shown in the Figure.

Figure 12: Quantification of plaque deposition in transgenic mice over-expressing the "Swedish/London" mutant amyloid precursor protein after immunization between 9.5 and 19 months of age. (A) Cortical plaque density. (B) Cortical plaque area. (C) Plaque density in the caudate putamen. (D) Plaque area in the caudate putamen. (E) Plaque density in the hippocampus. (F) Plaque area in the hippocampus. (G) Plaque density in the thalamus. (H) Plaque area in the thalamus. Plaque density is expressed in plaques/mm^2, plaque area in percent of tissue area covered by amyloid beta. Data are shown as individual values (black dots) and box plot. The ends of the boxes define the 25th and 75th percentiles, with a line at the median and error bars defining the 10th and 90th percentiles. ** $p<0.001$ (Mann Whitney Rank Sum Test). PBS, n=9, Qβ, n=11, QβhAβ1-6, n=16.

EXAMPLE 22

Immunisation with QβhAβ1-6 reduces amyloid plaques in transgenic mice over-expressing the "Swedish" mutant amyloid precursor protein.

This example demonstrates that immunization with QβhAβ1-6 provides an effective approach for the treatment of Alzheimer's disease even when the immunization is initiated in a very advanced stage of amyloid plaque pathology. The amyloid plaque deposition process in the AD mouse model used in this example starts already at an age about 6 months (Sturchler-Pierrat et al., 1997, Proc. Natl. Acad. Sci. 94: 13287-13292). In the study described herein, immunization with QβhAβ1-6 was initiated at an age of 18 months, where already a high number of compact plaques had been formed in the cortex. The example also demonstrates the ability of QβhAβ1-6 to induce Aβ40/42 antibodies in very aged animals (no non-responders in 19 immunized mice).

To evaluate the therapeutic effects of immunization with QβhAβ1-6 transgenic mice over-expressing the "Swedish" mutant amyloid precursor protein (APP23; K670N/M671L, Sturchler-Pierrat et al., 1997, Proc. Natl. Acad. Sci. 94: 13287-13292) were used. The Alzheimer's-like pathology in these mice has been extensively characterized (Calhoun et al., 1998, Nature 395: 755-756; Phinney et al., 1999, J. Neurosci. 19: 8552-8559; Bondolfi et al., 2002, J. Neurosci. 22: 515-522).

Human Aβ1-6 peptide coupled to Qβ VLP (QβhAβ1-6) was made as described in Example 13. In terms of the experimental procedure followed, which is not necessary for describing or enabling the invention, APP23 transgenic mice 18 months of age were injected subcutaneously at day 0 with 25 µg of QβhAβ1-6 dissolved in phosphate-buffered saline (administered as 2x100 µl per mouse) (n=19) or phosphate-buffered saline as a negative control (n=17) and boosted on day 13, 27-34, 61-63, 90-96, and 123-130 with 25 µg of vaccine. Animals were bled 1-2 days before the first immunization (day 0) and on day 41-45, and day 68 via the tail vein. Blood serum was also collected on day 152-154, at which time also brains were collected for histopathology (age of the mice at this time point: 23 months).

The titer of antibodies specific for Aβ1-40 were measured by ELISA essentially as described in Example 13 and the results expressed as described in Example 21. The results of the ELISA are shown in Fig. 14. All QβhAβ1-6

immunized mice developed OD50% titers above 1:2000 (pre-immune serum titers were below 1:100) demonstrating a consistent antibody response to Qβ-Aβ1-6 even in very old mice (Fig. 14). Median OD50% titers were in the range of 1:9'000 to 1:20'000 throughout the immunization period.

Quantification of amyloid plaques was done as described in Example 21. Data of each mouse were normalized to number of deposits (plaques) per mm^2 and total plaque area in % of the entire neocortex. QβhAβ1-6 immunized mice revealed a smaller number of deposits in the cortex (Figure 15, Fig. 16), mostly due to a reduction of small sized plaques. Compared to the non-immunized group the median plaque number was reduced by 33 % in the QβhAβ1-6 immunized group ($p< 0.001$ vs PBS-group, Mann-Whitney test). Since mostly small-sized plaques were affected the reduction of the total plaque area was moderate and amounted to 10 % ($p<0.01$ vs. PBS group, Mann-Whitney test).

Figure 14: Serum anti Aβ40/42 antibody titers (OD50%) in transgenic mice over-expressing the "Swedish" mutant amyloid precursor protein. Mice were immunized with QβhAβ1-6 between 18 and 23 months of age. Shown are individual values (black dots) and box plots, where the ends of the boxes define the 25th and 75th percentiles, with a line at the median and error bars defining the 10th and 90th percentiles (outlyers are shown as dots).

Figure 15: Immunhistochemical staining of amyloid plaques in sagittal brain sections. Arrows point to small sized deposits. Shown in the Figure is a sagittal brain section from a transgenic mouse over-expressing the "Swedish" mutant amyloid precursor protein immunized with PBS (A) or Qβ-Aβ1-6 (B).

Figure 16: Quantification of plaque deposition in transgenic mice over-expressing the "Swedish" mutant amyloid precursor protein after immunization between 18 and 23 months of age. (A) Cortical plaque density. (B) Cortical plaque area. Plaque density is expressed in plaques/mm^2 , plaque area in percent of tissue area covered by amyloid beta. Data are shown as individual values (black dots) and box plot. The ends of the boxes define the 25th and 75th percentiles, with a line at the median and error bars defining the 10th and 90th percentiles. ** $p<0.001$ (Mann Whitney Rank Sum Test). PBS, n=17, QβhAβ1-6, n=19.

Having now fully described the present invention in some detail by way of illustration and example for purposes of clarity of understanding, it will be obvious to one of ordinary skill in the art that the same can be performed by modifying or changing the invention within a wide and equivalent range of conditions, formulations and other parameters without affecting the scope of the invention or any specific embodiment thereof, and that such modifications or changes are intended to be encompassed within the scope of the appended claims.

All publications, patents and patent applications mentioned in this specification are indicative of the level of skill of those skilled in the art to which this invention pertains, and are herein incorporated by reference to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated by reference.

CLAIMS:

1. A composition comprising:

(a) a core particle with at least one first attachment site; and

(b) at least one antigen or antigenic determinant with at least one second attachment site,

wherein said antigen or antigenic determinant is a Aβ1-6 peptide, and wherein said second attachment site being selected from the group consisting of:

(i) an attachment site not naturally occurring with said antigen or antigenic determinant; and

(ii) an attachment site naturally occurring with said antigen or antigenic determinant,

wherein said second attachment site is capable of association to said first attachment site; and wherein said Aβ1-6 peptide and said core particle interact through said association to form an ordered and repetitive antigen array.

2. The composition of claim 1, wherein said core particle is selected from the group consisting of:

i) a virus;

ii) a virus-like particle;

iii) a bacteriophage;

iv) a virus-like particle of a RNA-phage;

v) a bacterial pilus;

vi) a viral capsid particle; and

vii) a recombinant form of (i), (ii), (iii), (iv), (v) or (vi).

3. The composition of any one of claim 1 or 2, wherein said core particle comprises, preferably is, a virus-like particle, wherein preferably said virus-like particle is a recombinant virus-like particle.

4. The composition of any one of claim 2 or 3, wherein said virus-like particle comprises recombinant proteins, or fragments thereof, selected from the group consisting of:

(a) recombinant proteins of Hepatitis B virus;
(b) recombinant proteins of measles virus;
(c) recombinant proteins of Sindbis virus;
(d) recombinant proteins of Rotavirus;
(e) recombinant proteins of Foot-and-Mouth-Disease virus;
(f) recombinant proteins of Retrovirus;
(g) recombinant proteins of Norwalk virus;
(h) recombinant proteins of Alphavirus;
(i) recombinant proteins of human Papilloma virus;
(j) recombinant proteins of Polyoma virus;
(k) recombinant proteins of bacteriophages;
(l) recombinant proteins of RNA-phages;
(m) recombinant proteins of Ty;
(n) recombinant proteins of Qβ-phage;
(o) recombinant proteins of GA-phage;
(p) recombinant proteins of fr-phage;
(q) recombinant proteins of AP205 phage; and
(q) fragments of any of the recombinant proteins from (a) to (q).

5. The composition of any one of claims 2 to 3, wherein said virus-like particle is Hepatitis B virus core antigen.

6. The composition of any one of claims 2 to 3, wherein said virus-like particle comprises, or alternatively consists of, recombinant proteins, or fragments thereof, of a RNA-phage.

7. The composition of claim 6, wherein said RNA-phage is selected from the group consisting of:

(a) bacteriophage Qβ;
(b) bacteriophage R17;
(c) bacteriophage fr;
(d) bacteriophage GA;
(e) bacteriophage SP;
(f) bacteriophage MS2;
(g) bacteriophage M11;
(h) bacteriophage MX1;
(i) bacteriophage NL95;
(k) bacteriophage f2;
(l) bacteriophage PP7; and
(m) bacteriophage AP205.

8. The composition of any one of claims 2 to 3, wherein said virus-like particle comprises, or alternatively consists of, recombinant proteins, or fragments thereof, of RNA-phage Qβ.

9. The composition of any one of claims 2 to 3, wherein said virus-like particle comprises, or alternatively consists of, recombinant proteins, or fragments thereof, of RNA-phage fr.

10. The composition of any one of claims 2 to 3, wherein said virus-like particle comprises, or alternatively consists of, recombinant proteins, or fragments thereof, of RNA-phage AP205.

11. The composition of any one of claims 3 to 10, wherein the recombinant proteins comprise, or alternatively consist essentially of, or alternatively consist of coat proteins of RNA phages.

12. The composition of claim 11, wherein said coat proteins of RNA phages having an amino acid are selected from the group consisting of:

(a) SEQ ID NO:4;

(b) a mixture of SEQ ID NO:4 and SEQ ID NO:5;

(c) SEQ ID NO:6;

(d) SEQ ID NO:7;

(e) SEQ ID NO:8;

(f) SEQ ID NO:9;

(g) a mixture of SEQ ID NO:9 and SEQ ID NO:10;

(h) SEQ ID NO:11;

(i) SEQ ID NO:12;

(k) SEQ ID NO:13;

(l) SEQ ID NO:14;

(m) SEQ ID NO:15;

(n) SEQ ID NO:16; and

(o) SEQ ID NO:28.

13. The composition of any one of claims 3 to 10, wherein the recombinant proteins comprise, or alternatively consist essentially of, or alternatively consist of mutant coat proteins of RNA phages.

14. The composition of claim 13, wherein said RNA-phage is selected from the group consisting of:

(a) bacteriophage Qβ;

(b) bacteriophage R17;

(c) bacteriophage fr;

(d) bacteriophage GA;

(e) bacteriophage SP;

(f) bacteriophage MS2;

(g) bacteriophage M11;

(h) bacteriophage MX1;

(i) bacteriophage NL95;

(k) bacteriophage f2;

(l) bacteriophage PP7; and

(m) bacteriophage AP205.

15. The composition of any one of claims 13 to 14, wherein said mutant coat proteins of said RNA phage have been modified by removal of at least one lysine residue by way of substitution.

16. The composition of any one of claims 13 to 14, wherein said mutant coat proteins of said RNA phage have been modified by addition of at least one lysine residue by way of substitution.

17. The composition of any one of claims 13 to 14, wherein said mutant coat proteins of said RNA phage have been modified by deletion of at least one lysine residue.

18. The composition of any one of claims 13 to 14, wherein said mutant coat proteins of said RNA phage have been modified by addition of at least one lysine residue by way of insertion.

19. The composition of any of the preceding claims, wherein said second attachment site is capable of association to said first attachment site through at least one covalent bond.

20. The composition of any of the preceding claims, wherein said second attachment site is capable of association to said first attachment site through at least one non-peptide bond.

21. The composition of any of the preceding claims, wherein said Aβ1-6 peptide is fused to said core particle.

22. The composition of any of the preceding claims, wherein said Aβ1-6 peptide is selected from the group consisting of:

(a) human Aβ1-6 peptide having an amino acid sequence of SEQ ID NO:75;

(b) murine Aβ1-6 peptidehaving an amino acid sequence of SEQ ID NO:76;

(c) primate Aβ1-6 peptide having an amino acid sequence of SEQ ID NO:84;;

(d) rabbit Aβ1-6 peptide having an amino acid sequence of SEQ ID NO:85;

(e) xenopus laevis Aβ1-6 peptide having an amino acid sequence of SEQ ID NO:86;

(f) rat Aβ1-6 peptide havingan amino acid sequence of SEQ ID NO:87; and

(g) guinea pig Aβ1-6 peptide having an amino acid sequence of SEQ ID NO:88.

23. The composition of any of the preceding claims, wherein said Aβ1-6 peptide has an amino acid sequence of SEQ ID NO:75.

24. The composition of any of the preceding claims further comprising an amino acid linker, wherein said amino acid linker comprises, or alternatively consists of, said second attachment site.

25. The composition of any of the preceding claims, wherein said second attachment or said amino acid linker with said second attachment site is bound to said Aβ1-6 peptide at its C-terminus.

26. The composition of any of the preceding claims, wherein said second attachment site or said amino acid linker with said second attachment site is selected from the group consisting of:

(a) GGC;

(b) GGC-CONH2;

(c) GC;

(d) GC-CONH2;

(e) C; and

(f) C-CONH2.

27. The composition of any of the preceding claims, wherein said Aβ1-6 peptide with said at least second attachment site is NH2-DAEFRHGGC-CONH2 (SEQ ID NO: 77).

28. The composition of claim 27, wherein said virus-like particle is a virus-like particle of RNA-phage Qβ coat protein.

29. A pharmaceutical composition comprising:

(a) the composition of claim 1; and

(b) an acceptable pharmaceutical carrier.

30. The pharmaceutical composition of claim 29 further comprising an adjuvant.

31. The pharmaceutical composition of claim 29 or claim 30, wherein said vaccine composition is devoid of an adjuvant.

32. A vaccine composition comprising the composition of any of the preceding claims.

33. The vaccine composition of claim 32, further comprising an adjuvant.

34. The vaccine composition of claim 32 or claim 33, wherein said vaccine composition is devoid of an adjuvant.

35. The vaccine composition of any one of claims 32 to 34, wherein said virus-like particle comprises recombinant proteins, or fragments thereof, of a RNA-phage.

36. The vaccine composition of any one of claims 32 to 35, wherein said virus-like particle comprises recombinant proteins or fragments thereof, of RNA-phage Qβ.

37. The vaccine composition of any one of claims 32 to 35, wherein said virus-like particle comprises recombinant proteins, or fragments thereof, of RNA-phage fr.

38. The vaccine composition of any one of claims 32 to 35, wherein said virus-like particle comprises recombinant proteins, or fragments thereof, of RNA-phage AP205.

39. The vaccine composition of any one of claims 32 to 38, wherein said Aβ1-6 peptide is selected from the group consisting of:

(a) human Aβ1-6 peptide having an amino acid sequence of SEQ ID NO:75;

(b) murine Aβ1-6 peptidehaving an amino acid sequence of SEQ ID NO:76;

(c) primate Aβ1-6 peptide having an amino acid sequence of SEQ ID NO:84;;

(d) rabbit Aβ1-6 peptide having an amino acid sequence of SEQ ID NO:85;

(e) xenopus laevis Aβ1-6 peptide having an amino acid sequence of SEQ ID NO:86;

(f) rat Aβ1-6 peptide havingan amino acid sequence of SEQ ID NO:87; and

(g) guinea pig Aβ1-6 peptide having an amino acid sequence of SEQ ID NO:88.

40. The vaccine composition of any one of claims 32 to 39 further comprising an amino acid linker, wherein said amino acid linker comprises, or alternatively consists of, said second attachment site.

41. The vaccine composition of claim 40, wherein said amino acid linker with said second attachment site is bound to said Aβ1-6 peptide at its C-terminus.

42. The vaccine composition of any one of claims 40 to 41, wherein said amino acid linker with said second attachment site is selected from the group consisting of:

(a) GGC;
(b) GGC-CONH2;
(c) GC;
(d) GC-CONH2;
(e) C; and
(f) C-CONH2.

43. The vaccine composition of any one of claims 32 to 42, wherein said antigen or antigenic determinant with said at least second attachment site is NH2-DAEFRHGGC-CONH2 (SEQ ID NO: 77).

44. The vaccine composition of claim 43, wherein said virus-like particle is a virus-like particle of RNA-phage Qβ coat protein.

45. A process for producing a composition of any of the preceding claims comprising:

(a) providing a core particle with at least one first attachment site;
(b) providing at least one antigen or antigenic determinant with at least one second attachment site,

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wherein said antigen or antigenic determinant is a Aβ1-6 peptide, and wherein said second attachment site being selected from the group consisting of:

(i) an attachment site not naturally occurring with said antigen or antigenic determinant; and

(ii) an attachment site naturally occurring with said antigen or antigenic determinant; and

wherein said second attachment site is capable of association to said first attachment site; and

(c) combining said core particle and said at least one antigen or antigenic determinant, wherein said antigen or antigenic determinant and said core particle interact through said association to form an ordered and repetitive antigen array.

46. The use of the composition of any of the preceding claims in the preparation of a medicament for immunization.

47. The use of the composition according to claim 46 in the preparation of a medicament for immunization, wherein said antigen or antigenic determinant is a self-antigen.

48. The use of the composition according to any one of claims 46 to 47, in the preparation of a medicament for immunization.

49. The use of the composition according to any one of claims 46 to 48 in the preparation of a medicament for immunization, wherein said antigen or antigenic determinant is human Aβ1-6 peptide.

50. Composition of any one of claims 1 to 44 for use as a medicament.

51. Use of a composition of any one of claims 1 to 44 for the manufacture of a medicament for treatment of Alzheimer and related diseases.